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Prepared for:
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

# FOREWORD

This NBS Interagency/Internal Report (NBSIR) documents the results of the National Bureau of Standards (NBS) research in support of the Naval Civil Engineering Laboratory in fulfillment of NCEL/NBS Interagency Agreement, entitled, "Daylight and Energy Evaluation of Industrial Buildings" contract No. 84WR40050. The report summarizes work conducted during the period October 1983 through December 1984.

ABSTRACT

This report investigates the relationship between building energy requirements for heating, cooling and lighting, and building fenestration design. Particular emphasis is given to the effect of the use of daylight to offset electric lighting needs. The computer simulation procedure used for the analysis is a hybrid version of BLAST and CEL-1, which allows detailed modeling of building heat transfer, HVAC systems, and lighting systems.

The evaluation encompasses five locations, and the results are presented in the form of generalized design guidelines and figures, on the basis of building thermal mass and exposed wall area.

Keywords: Computer simulation, daylighting, energy, fenestration, illuminance, skylight, window.

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# 1. INTRODUCTION

The building industry directly or indirectly touches on a large segment of the Nations's economy, including building designers, constructors, operators, and users. Quality in the built environment can be considered essential, mandating efficient and effective use of materials, labor, and operating resources.

Building energy requirements due to heating, cooling, and lighting loads constitute a significant portion of National energy usage and annual building operating expenses. Building energy usage is influenced by a variety of factors, ranging from site and location parameters, to building envelope design, to HVAC system performance, to control strategies [1, 2, 3]. Each of the stages in the design, construction, and operation of a building offer the opportunity for reasoned decisions among various alternatives leading to a successful, useful building. A uninformed choice at a critical decision point can compromise the effectiveness of an otherwise sound design or plan of operation.

Many critical building design decisions must be made very early in the design process. Building height, number of floors, floor area, and general site orientation may be among the first building parameters to be chosen. These seemingly basic and simple decisions have a strong influence on the eventual final design of the building by setting constraints on potential design options. This is particularly true for issues related to the design of the building envelope, such as fenestration type, design, and size. Top-lighting with sky-lights or other overhead fenestration can only be implemented in building zones with access to the roof surface. Window design is linked to wall design, and energy concerns must be combined with structural considerations. The design of building interiors is also related to the design of the envelope, since interior partition walls and room layout can influence daylight distribution from fenestration elements.

In response to the need for procedures for assisting the design of good buildings, mathematical models and computer simulation techniques have been developed to enable evaluation of the relative merit of various design alternatives. Some of the most powerful building energy simulation computer programs calculate annual building energy requirements using hourly time increments. Programs such as DOE 2 [ 24 ], BLAST [7], and NBSLD [9, 10] have been widely used. These programs allow the detailed simulation of heat transfer between the building and the environment, occupant energy-related factors, and HVAC system performance. Lighting is not modeled explicity, but is considered as a heat load in the internal heat balance, with a prespecified magnitude, varying according to a lighting schedule and/or daylight level. The effects of daylighting on lighting energy loads are estimated by assuming a relationship between lighting power consumption and light levels at the task points, and controlling the lighting power to maintain a constant illumination level at the task points [8, 11, 12, 13].

The initial assumption of maximum lighting power and illumination setpoint are not independent, since luminaire design and placement, and room surface reflectances can influence the illuminance distribution from an actual lighting

system. That is, a maximum lighting power of one kilowatt and illuminance level of 1000 lux might be specified for a 100 $m^2$ room. However, there is no guarantee that a one kilowatt lighting system will provide an illuminance level of 1000 lux for that particular installation. The actual relationship between lighting power and illuminance levels can only be established by detailed modeling of the lighting system. This can either be done in advance by hand calculations or other means [4, 5, 6], or by using the hybrid BLAST/CEL-1 computer program presented here.

The capability of combining detailed hourly simulations of building heat transfer and energy requirements together with the lighting and daylighting performance is unique to this hybrid version of BLAST/CEL-1.

The purpose of this report is to investigate through computer simulation the relationship between fenestration design and building energy performance. The effect of variations in fenestration type, size, and location on heating, cooling, and lighting loads is examined for different building types and geographical locations. Building type variations evaluated include wall and ceiling thermal mass and amount of wall exposure.

The basic building zone evaluated was a single, open-plan box-like structure. Similar industrial-type spaces are used for warehouses, maintenance, assembly, and numerous other activities. In addition, virtually identical spaces are used for retailing, public and educational activities.

While there is no single "typical" industrial building, industrial-type buildings do have some characteristics which tend to make them a unique class of buildings. Some of these characteristics are:

- open plan
- high ceilings
- single floor
- flexible interior use requirements
- internal equipment loads

Many industrial buildings actually consist of attached work and office areas. Office design requirements and options may be different from industrial space requirements, primarily due to differences in building geometry, layout and occupant activities. However, the results of this analysis of industrial buildings may be applicable to similar office spaces. A subsequent report will examine daylighting issues related to office spaces. From the point-of-view of building energy analysis, it is useful to evaluate industrial spaces and office spaces separately, enabling the determination of the best characteristics of each type of space. A combined industrial/office building can then be assembled from the individual best industrial and office spaces.

The analysis focuses on single-zone energy performance for a large open zone. In some cases, the zone is modeled as a freestanding building. In other cases, the zone is modeled as if it were adjacent to similar zones on three sides.

## 2. BACKGROUND

To investigate the influence of fenestration design on building energy requirements, a series of computer simulations was carried out. Sixty-four building/fenestration combinations were evaluated for each of five geographical locations. The fenestration designs included skylights, sawtooth structures, and windows of various sizes. Each building consisted of either a freestanding single, open zone, 60 ft wide by 60 ft long by 30 ft high, (18.3 x 18.3 x 9.1 m) or a single zone of the same size with other conditioned zones on three sides ( i.e., as if part of a larger building).

Since the intent of the analysis was to evaluate industrial-type buildings, single-zone evaluations were considered to be the most useful and general. Unless there are strong interactions between adjacent zones in a single building, as would be the case if adjacent zones were operated at significantly different temperatures, single-zone analysis is sufficient to isolate the influence of fenestration on the zone heating, cooling, and electric requirements. Multiple-zone analysis also requires a much larger number of simulations to account for all of the various combinations of different adjacent zones.

A hybrid version of BLAST and CEL-1 was used to perform the computer simulations. The BLAST program allows the simulation of heat transfer between the building and its environment, and the associated energy requirements for space conditioning. The CEL-1 program enables detailed simulation of the lighting systems, including daylighting effects, providing lighting power information to BLAST. CEL-1 allows the modeling of actual luminaires, interior obstructions, drapes, blinds, light shelves, skylights, clerestories, sawtooth structures, and exterior obstructions.

### 2.1 Summary of Procedure for Executing BLAST/CEL-1

When using BLAST/CEL-1, separate BLAST and CEL-1 input files must be established for each zone. Once the appropriate files have been assembled, a custom updated version of BLAST is executed, with the BLAST input file calling for report 26. As part of the initial BLAST tasks, a system utility is called which freezes BLAST and causes CEL-1 to execute. At this time a lighting power multiplier table is computed for each zone and stored on disk. When CEL-1 is finished, control is returned to BLAST. Later, for each zone during the hourly loop of the energy calculations, BLAST calls an interpolation subroutine, sending it diffuse and direct normal irradiance, solar altitude, and solar azimuth. The subroutine interpolates among the table of precalculated values on the basis of the four input parameters, thereby determining the fraction of lighting power required for each zone according to the daylight control scheme listed in the CEL-1 input file. The details of the input file structure and program execution are contained in related reports [17, 18, 25].

## 3. DESCRIPTION OF SIMULATIONS

### 3.1. LOCATIONS

Simulations were performed for five locations around the contiguous United States. The locations and their heating and cooling degree days are:

| | (Base 65°F)* | |
|---|---|---|
| | Heating Degree Days | Cooling Degree Days |
| Boston, Massachusetts | 5760 | 700 |
| Norfolk, Virginia | 3294 | 1378 |
| Miami, Florida | 147 | 4272 |
| San Diego, California | 1188 | 642 |
| Seattle, Washington | 5401 | 142 |

*(Divide these values by 1.8 for base of 18.3°C)

Figure 1 presents a plot which demonstrates the different climates graphically.

## 3.2 BUILDINGS

One-hundred-and-twenty-eight simulations were run for each location, one-half freestanding buildings and the other one-half subsections of a larger building (see figure 2). The annual energy usage for each of the buildings was calculated both with and without daylight utilization. The with-daylighting cases mean daylight was used to offset electric lighting requirements, while the nondaylighting cases mean lighting was left full-on, varying only by the lighting schedule. The building walls were either brick or metal, with a slab-on-grade floor of area 3600 $ft^2$ (334 $m^2$). Each of the buildings differed in their wall construction, fenestration design or size, and/or number of exposed walls.

Eight series of sixteen buildings were simulated for each location, according to the following matrix.

Table 1 Simulation Parameter Matrix

| Parameter | Series 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| Brick (B) or Metal (M) | B | B | B | B | M | M | M | M |
| Freestanding (F) or Attached (A) | F | F | A | A | F | F | A | A |
| Daylighting-Yes (Y) or No (N) | N | Y | N | Y | N | Y | N | Y |

The foregoing combinations of parameters were selected to enable evaluation of the dependence of fenestration design on building envelope thermal mass, and exposed wall area. With more massive envelope construction, heating and cooling load patterns can be shifted in time and changed in magnitude. A freestanding building would probably have a higher ratio of heating to cooling loads than an attached building zone of the same size, since the greater surface area would lead to more thermal heat loss through the walls. Both of these effects can potentially influence the best daylighting designs, since daylight enters buildings spaces as a fraction of the solar gain leading to tradeoffs between solar gains, daylight levels, and lighting loads.

Each simulation series consisted of sixteen buildings of identical construction with the exception of the fenestration design. Table 2 lists the fenestration options.

Table 2 Fenestration Design Options

| Building Zone | Type | Size | Effective Aperture |
|---|---|---|---|
| 1 | None | - | 0. |
| 2 | Skylights | 1% of roof | 0.008 |
| 3 | Skylights | 2.25% of roof | 0.018 |
| 4 | Skylights | 4% of roof | 0.032 |
| 5 | South sawtooth | 5% of roof | .04 |
| 6 | South sawtooth | 10% of roof | .08 |
| 7 | South sawtooth | 20% of roof | .16 |
| 8 | South window | 10% of wall | .08 |
| 9 | South window | 20% of wall | .16 |
| 10 | South window | 40% of wall | .32 |
| 11 | North sawtooth | 5% of roof | .04 |
| 12 | North sawtooth | 10% of roof | .08 |
| 13 | North sawtooth | 20% of roof | .16 |
| 14 | North window | 10% of wall | .08 |
| 15 | North window | 20% of wall | .16 |
| 16 | North window | 40% of wall | .32 |

Effective apperture is defined as the product of the glazing transmittance and the ratio of fenestation area to wall area (for windows) or ceiling area (for skylights and sawtooth structures). All glazings were modeled as double-pane, one clear and the other diffuse, with a visible transmittance of 0.80. No supplementary shading was modeled. The skylighted buildings had nine skylights, symetrically spaced (see figure 3). The sawtooth designs consisted of three elements, each one-third of the building width by the entire length, with the vertical surfaces glazed. The windows were located at the top of the wall, and were not intended to provide a view out of the building. The purpose of the various fenestration designs was to identify the influence of fenestration type, size, and location on energy requirements. Table 3 lists a description of the basic building types, and table 4 describes the building envelope construction details.

Dead-band temperature control was used with setpoints of 68°F (20°C) minimum and 78°F (25.6°C) maximum. The buildings were assumed to have 30 occupants and a fixed electric load of 1800 watts, consisting of equipment and lighting. The primary lighting system was modeled as six banks of fluorescent luminaires, running parallel to the sawtooth or window glazings, with a maximum power level of 6480 watts (1.8 watts per $ft^2$, 19.37 watts per $m^2$). The luminaires each had four tubes, four feet long, and were 100 percent downlight. They were mounted at the nominal roof plane (i.e., flush with the flat ceiling, except for the sawtooth cases in which the luminaires were maintained at the same locations but the roof sections were tilted to allow for exposed vertical glazing surfaces). Preliminary modeling of the lighting system showed an average illumination level of slightly over 50 fc (538 lux) with the lights fully powered, so this level was chosen as the design illumination setpoint. The dimming control system was modeled as varying light output and power consumption linearly from full on to 30 percent, with a minimum power consumption of 30

Table 3. Building Descriptions

| | |
|---|---|
| Building Dimensions | 60 ft (18.3 m) long<br>60 ft (18.3 m) wide<br>30 ft ( 9.1 m) high |
| Building Type | Single Floor<br>Slab-on-grade<br>No Attic Space<br>1) Brick, Freestanding<br>2) Brick, Attached<br>3) Metal, Freestanding<br>4) Metal, Attached |
| Building Use | Industrial |
| Building Thermal Properties | Insulated Roof and Exterior Walls<br>Double-pane Glazing |

percent. This is typical of fluorescent dimmer performance. The control criterion was average illuminance at sixteen points, a symmetric four by four matrix. Table 5 summarizes the design parameters used for the analysis. Figure 4 presents the layout of the lighting system.

### 3.3 SIMULATION INPUT

Separate BLAST and CEL-1 input files were established for each simulation series. Details on the input file structure and execution procedures can be found in other publications [ 7, 18, 25]. A general description of the input file parameters follows.

The general procedure for running BLAST and CEL-1 is to assemble the required building information and translate that into BLAST and CEL-1 input files. The BLAST input file includes:

- building location
- simulation period
- building geometry
- components of building elements (walls, etc.)
- heating and cooling control strategy
- other energy requirements (lighting, etc.)
- other loads (people, etc.)
- infiltration
- system description (optional)
- plant description (optional)

If only loads are to be determined, system and plant descriptions are not needed. Other parameters may either be optional or assigned default values. For convenience in running a large number of simulations, sixteen buildings were simulated in each run as separate isolated zones of a single building.

Table 4. Building Envelope Construction Details

| Component | Area | Overall Thermal Conductance | Layer | Thickness | |
|---|---|---|---|---|---|
| | $Ft^2$ ($m^2$) | $\frac{Btu}{H \cdot FT^2 \cdot F}$ ($\frac{W}{m^2 \cdot k}$) | | in. | (cm) |
| Floor | 3600 (334) | 0.091 (0.517) | Concrete Slab | 4 | (10.2) |
| Exterior Wall | 7200 (669) or 1800 (167) | 0.104 (0.590) | Face Brick | 4 | (10.2) |
| | | | Insulation | 2 | ( 5.1) |
| | | | Lightweight Concrete Block | 4 | (10.2) |
| | | | Gypsum Board | 0.75 | ( 1.9) |
| | | | or | | |
| | | 0.133 (0.755) | Steel Siding | - | |
| | | | Insulation | 2 | ( 5.1) |
| | | | Steel Siding | - | |
| Partition Wall | Zero or 5400 (502) | 0.376 (2.13) | Gypsum Board | 0.75 | ( 1.9) |
| | | | Lightweight Concrete Block | 4 | (10.2) |
| | | | Gypsum Board | 0.75 | ( 1.9) |
| | | | or | | |
| | | | Gypsum Board | 0.75 | ( 1.9) |
| | | | Airspace | 3.5 | ( 8.9) |
| | | | Gypsum Board | 0.75 | ( 1.9) |
| Roof | *3600 (334) | 0.092 (.517) | Slag or Stone | 0.5 | ( 1.3) |
| | | | Felt and Membrane | 0.375 | ( 1.0) |
| | | | Insulation | 2 | ( 5.1) |
| | | | Concrete | 4 | (10.2) |
| | | | Airspace | 1 | ( 2.5) |
| | | | Acoustical Tile | 0.75 | ( 1.9) |
| Windows | 180 360 720 (17 33 67) | .553 (3.14) | | | |
| Skylights | 36 81 144 (3 8 13) | .553 (3.14) | | | |
| Sawtooth | 180 360 720 (17 33 67) | .533 (3.14) | | | |

* Assuming no roof fenestration

Table 5. Parameters Used for Analysis

| | | |
|---|---|---|
| 1) Thermostat Setpoints Dead-Band Control | min. 68°F (20.0°C)<br>max. 78°F (25.6°C) | |
| 2) Occupancy Schedule | hours 1-6 | Unoccupied |
| | hour 7 | 10% occupied |
| | hour 8 | 50% occupied |
| | hours 9-12 | 100% occupied |
| | hour 13 | 50% occupied |
| | hours 14-16 | 100% occupied |
| | hour 17 | 50% occupied |
| | hour 18 | 10% occupied |
| | hours 19-24 | Unoccupied |
| | weekends | Unoccupied |
| | holidays | Unoccupied |
| 3) Number of Occupants | 30 | |
| 4) Electric | 1.7 $Btuh^{-1}$ per $ft^2$<br>5.38 watts per $m^2$<br>1800 watts total | |
| 5) Lighting | 1.8 watts per $ft^2$<br>19.37 watts per $m^2$ | Primary fluorescent luminaires controlled in six banks |
| | 6480 watts total | Linear dimming from 100 to 30 percent light output (minimum) 100% lighting power dissipated as heat to interior space |
| | Illumination Setpoint | 50 fc (538 lux) |

90ch of the zones has a corresponding CEL-1 input file. Thus, a BLAST input file with sixteen zones requires a set of sixteen CEL-1 input files. In the sixteen zone BLAST input file, the zones are numbered one through sixteen, the corresponding CEL-1 input files are named CELDDn, where n equals the BLAST zone number. The CEL-1 input file includes:

- zone geometry
- surface transmittances and reflectances
- lighting system description
- task locations
- fenestration design

To make the building simulation process more manageable, several techniques are useful for reducing the complexity of the input files or the simulation computer time. Building geometry can be considerably simplified, usually with insignificant effect on the simulation accuracy. Within CEL-1 rather than simulating 36 individually controllable luminaires, six rows of six, each row can be combined into a single quasi-luminaire. The quasi-luminaire has the same total light output, power consumption, and photometric distribution as six actual luminaires. However, instead of a row of six discrete 2 by 4 luminaires, a single luminaire with the same span is substituted. This results in six individually controlled luminaires rather than 36, a considerable savings in simulation requirements. This lumping of the luminaires has little effect on the results as long as the group of luminaires being combined are exposed to similar conditions. In this case, since the luminaire rows run parallel to the window wall, each row would be expected to dim together.

## 3.4 SIMULATION OUTPUT

Since the purpose of the investigation was to focus on the effect of fenestration design on building energy requirements, a particular building HVAC system or plant was not simulated. Rather, building heating, cooling, and electric loads were calculated and converted into energy by assuming constant heating efficiency and cooling coefficient of performance. These loads are more sensitive to changes in envelope design than are system energy requirements. In addition, since the simulation of a system requires the selection of the HVAC system appropriate for the loads, system sizing and performance characteristics are dependent upon envelope design and weather. This makes it difficult to establish a baseline for comparisons of fenestration designs.

The primary output parameters for each building zone simulation are:

- peak heating load
- peak cooling load
- annual electric load
- annual heating load
- annual cooling load
- annual total energy use

Peak heating and cooling loads are important for sizing HVAC equipment, with smaller peak loads meaning smaller equipment sizes. Also, the magnitude and timing of peak electric requirements influence the cost of electric energy by impacting the rate structure. In many cases, the per unit cost of electricity is a function of maximum hourly electric demand.

The separate annual heating and cooling loads represent the energy added or extracted from the building space, not the energy used by the system to condition the space. System energy for heating was determined by assuming a heating efficiency of 80 percent, and cooling energy was determined by assuming a coefficient of performance of three. Electric loads and energy are equal. Annual total energy is the sum of electric, heating, and cooling energies. This annual total is presented on a per unit area basis.

## 4. RESULTS

Generalizations about the simulation results are difficult to make due to the large number of simulations and parameters, and the strong influence of location on the building loads. However, some general comments about trends are appropriate. Detailed discussions of the results for each location will be described in separate subsections to follow. Topics for evaluation include the effects of:

a) Daylighting versus no-daylighting
b) Fenestration type - skylight, sawtooth or window
c) Fenestration size, orientation
d) Thermal mass of building
e) Freestanding versus attached building
f) Location

Daylighting was seen to be beneficial for all locations. That is, at least some fenestration options lead to lower annual energy requirements than for the zero fenestration option. Also, for any fenestration option, annual energy requirements for the daylighting cases were less than for the non-daylighting cases. This was due to a significant decrease in lighting energy, coupled with a smaller decrease in cooling energy. Heating energy requirements increased when daylighting was used, but this change was usually small in comparison with the decreases in cooling and electric energy.

Peak heating loads were not influenced by daylighting, since peak heating requirements typically occur in early morning hours when lighting is not used. Peak cooling loads, however, decrease when daylighting is used, since peak cooling requirements usually correspond to times when daylight is abundant.

Table 6 presents the best effective apperture, among those that were simulated, for each fenestration type at each location. The best effective aperture is the one which provided the minimum annual energy consumption for the building. If a range of effective apertures provided nearly equivalent energy performance, the range of equivalent effective apertures is listed in parenthesis under the best effective aperture. In addition, the ratio of energy use with the best effective aperture to that with no fenestration is listed for each case.

Table 6. Best Effective Aperture and Energy Ratio

| Fenestration Type | Miami | | San Diego | | Norfolk | | Boston | | Seattle | |
|---|---|---|---|---|---|---|---|---|---|---|
| | EA | ER | EA | ER | EA | ER | EA | ER | EA | ER |
| Skylights | .018 (.018-.032) | .77 | .032 (.018-.032) | .75 | .032 (.018-.032) | .89 | .032 (.018-.032) | .75 | .032 (.018-.032) | .89 |
| South Sawtooth | .04 (--) | .76 | .04 (.04-.08) | .72 | .16 (.08-.16) | .86 | .08 (.04-.16) | .95 | .08 (.04-.16) | .95 |
| North Sawtooth | .04 (--) | .74 | .04 (.04-.08) | .73 | .04 (--) | .94 | .04 (--) | .99 | .04 (.0-.04) | .99 |
| South Window | .16 (--) | .81 | .16 (--) | .74 | .32 (--) | .83 | .32 (--) | .90 | .32 (--) | .91 |
| North Window | .16 (--) | .80 | .16 (.16-.32) | .76 | .16 (--) | .94 | .16 (.08-.16) | .99 | .16 (.08-.16) | .99 |

EA - best effective aperture = glazing transmittance x area ratio

ER - energy ratio = ratio of annual energy use with best effective aperture to annual energy use with no fenestration (averaged for four building types).

be determined for each fenestration type, and different fenestration types can be compared to determine the most energy efficient.

Several conclusions can be drawn from table 6, as follows:

- For the north-facing sawtooth, the best effective aperture was 0.04 for all the building types and locations. This is primarily due to the high levels of daylight from the sawtooth causing the lighting to dim to its minimum level, so that increasing sawtooth size did not decrease lighting energy requirements.

- For the north-facing windows, the best effective aperture was 0.16 for all the building types and locations. This can be attributed to the trade-off between daylight gains and thermal losses due to the north-facing glazings, which are not good solar collectors, and therefore, provide little heating benefit. The locations with higher heating requirements exhibited broad minimums between effective aperture of 0.08 to 0.16.

- For the skylights, the best effective aperture was 0.018 for the location with a high ratio of cooling to heating degree days, and 0.032 for the other locations. Results were the same for all building types.

- For the south-facing sawtooth, the best effective aperture was 0.04 for the warmer locations, increasing to 0.16 for Norfolk, followed by a decrease to 0.08 for the colder climates. However, a broad range of minimum energy consumption was observed for the colder climates, with virtually equivalent energy performance for effective aperture from 0.04 to 0.16.

- For the south-facing windows, the best effective aperture was 0.16 for the warmer climates and 0.32 for the rest of the locations.

- Daylighting was most effective in San Diego followed closely by Miami. Energy reductions of over 25 percent were seen to occur for those locations. Reductions of over 15 percent were found for Norfolk and 10 percent for Boston and Seattle.

- For Miami, skylights and either sawtooth were equally effective, while for San Diego energy savings were similar for all fenestration types. South-facing windows were best in Norfolk, Boston, and Seattle.

Figure 5 presents a plot of best effective aperture for each fenestration type versus the logarithm of the ratio of heating degree days to cooling degree days at each of the locations. The log form is used to compress the horizontal scale. Heating dominated climates appear as positive numbers, while cooling dominated climates result in negative numbers. This plot is a graphical representation of table 6.

Figures 6 through 30 present the ratios of energy use with daylighting for each fenestration type and size to energy use with no fenestration for each location. From these figures it can be seen that:

- Building type had very little effect on the shape of the curves and the minimum energy points. Thus, the best effective aperture was the same for all building types at a single location.

- The attached buildings, in general, used less energy, as would be expected, but exhibited the same relative sensitivity to fenestration design as the free standing buildings.

Daylight illuminance levels from the sawtooth structures were such that even for the smallest sawtooth glazings, the electric lighting was usually at its minimum. This suggests that even smaller sawtooth glazings might be energy effective, although the minimum glazing height modeled was 1 ft (0.3 m). The effect of fenestration orientation was related to building location. For the colder climates, south-facing windows and sawtooths were more beneficial than north-facing, due to the solar gains through the south-facing glazings. In warmer climates, the reverse was true, since south-facing fenestrations tend to increase cooling requirements. The optimum fenestration size, for each fenestration type, varied by location as described earlier.

Building thermal mass influenced loads and energy in several ways. Heating loads were greater for the lightweight metal building than for the brick, block, and concrete building, while the cooling loads were about the same. Total annual energy requirements were less for the brick building than for the metal building due to slight differences in the steady-state thermal resistances, but the relative effective of fenestration size was similar. Peak heating and cooling loads were less for the heavy mass building than for the light metal building.

The freestanding buildings had higher ratios of heating loads to cooling loads than similar buildings with only one exposed wall. This factor tends to make daylighting more beneficial for the attached buildings, although daylighting is favorable for both building types.

Examining all of the locations together provides a means for evaluating the effect of climate conditions on optimum design of fenestration. Each of the locations studied had a different combination of heating and cooling loads. Boston has high heating loads and moderate cooling loads. Norfolk has moderate heating and cooling loads. Miami has high cooling loads and low heating loads, while San Diego has moderate cooling requirements and low heating loads. Seattle has high heating requirements but low cooling loads. As a result of these combinations, fenestration design guidelines tend to vary by location. North-facing glazings are favored for locations with high cooling loads, while south-facing glazings are best for regions with high heating loads. Optimum fenestration size was not particularly sensitive to location for north-facing fenestration types.

## 4.1 MIAMI

Figures 31 through 58 present total annual energy usage with and without daylight for the various building types and fenestration designs for Miami. Figures 59 through 78 show the individual heating, cooling, and electric loads for the

simulated year. Figures 79 through 98 present the peak heating and cooling loads. From these figures, daylighting is seen to be very beneficial with savings of over 25 percent in annual energy usage, compared to the zero fenestration case. The north sawtooth was most effective, followed by the south sawtooth and skylights. The nondaylighting buildings with fenestration always used more energy than the zero fenestration base case.

Most of the energy savings is due to reduced lighting requirements, with reduced cooling loads also occurring at the lower fenestration effective apertures. Since heating loads were nearly nonexistant, the influence changes in heating energy was negligible.

## 4.2 SAN DIEGO

Figures 99 through 126 present total annual energy usage for the San Diego simulations. Figures 127 through 146 present the heating, cooling, and electric loads, and figures 147 through 166 present the peak heating and cooling loads. Energy savings due to daylighting reached 28 percent for the optimum fenestration effective apertures with all fenestration types and orientation performing almost equally well.

Most of the energy savings is due to reductions in lighting energy requirements, with cooling energy reductions at the lower fenestration sizes.

## 4.3 NORFOLK

Figures 167 through 194 present the total annual energy usage for the Norfolk simulations. Figures 195 through 214 show the individual heating, cooling, and electric loads, and figures 215 through 234 present the peak heating and cooling loads. The south-facing window is the best performer, providing a 17 percent reduction in annual energy usage. The south sawtooth and skylights provided more than 10 percent reduction.

Heating loads increased and cooling loads decreased due to daylighting, combining with lighting energy reductions to cause an overall savings in annual total energy, but not as great a savings as San Diego or Miami.

## 4.4 BOSTON

Figures 235 through 262 present annual energy usage for the Boston simulations. Figures 263 through 282 show the individual heating, cooling, and electric loads, while figures 283 through 302 present the peak heating and cooling loads. The south-facing window provided the best energy performance, a 10 percent reduction compared to zero fenestration. The skylights and south sawtooth provided a 5 percent reduction. The two north-facing fenestration types were marginally beneficial for at least one size. The north sawtooth was only effective for the smallest effective aperture.

## 4.5 SEATTLE

Figures 303 through 330 present the total annual energy usage for the Seattle simulations. Figures 331 through 350 show the individual heating, cooling, and electric load components. Figures 351 through 370 show the peak heating and cooling loads. these results show that daylighting was least effective for this location, although a 9 percent reduction was seen for the south-facing window. The skylights and south sawtooth were also favorable.

Energy savings are less for Seattle due to relatively low availability of sunlight and very low cooling loads. thus, the lighting and cooling benefits are less than those for the other locations.

# 5. CONCLUSIONS

An extensive series of annual building energy simulations was conducted for different building types at five locations to evaluate the influence of fenestration design and daylighting on building energy performance. The results of the simulations show that daylighting can be effective at reducing building energy requirements by reducing lighting and cooling loads. Heating loads increased with daylight utilization, but the net effect was beneficial for the location considered.

Building type (lightweight versus heavyweight) and design (free standing versus attached) did not influence the relative effect of fenestration design. Thus, the optimum size of each fenestration type was not dependent upon building type. Optimum fenestration size did vary with geographical location and fenestration type. Interestingly, the optimum size for the north sawtooth and south windows was independent of location and building type. This can be attributed to the trade-offs between daylight gains and thermal losses through north-facing glazings.

Daylighting was seen to be most beneficial for locations with low ratios of heating to cooling loads, such as San Diego and Miami. However, some fenestration option with daylighting was always better than the zero fenestration (no daylighting) case.

Peak cooling loads were reduced due to daylighting, while peak heating loads were unaffected.

The results of this study can be used during the initial design stages to enable the preliminary determination of fenestration type and size. As the building design process progresses, more detailed simulations can be executed to determine the best fenestration characteristics for the actual building, using actual building parameters.

Further research is needed to evaluate the effects of variations in fenestration shading coefficient and variable window management options. Use of operable shading devices, such as shades, blinds and louvers, should influence fenestration performance, and thus impact fenestration design optimums.

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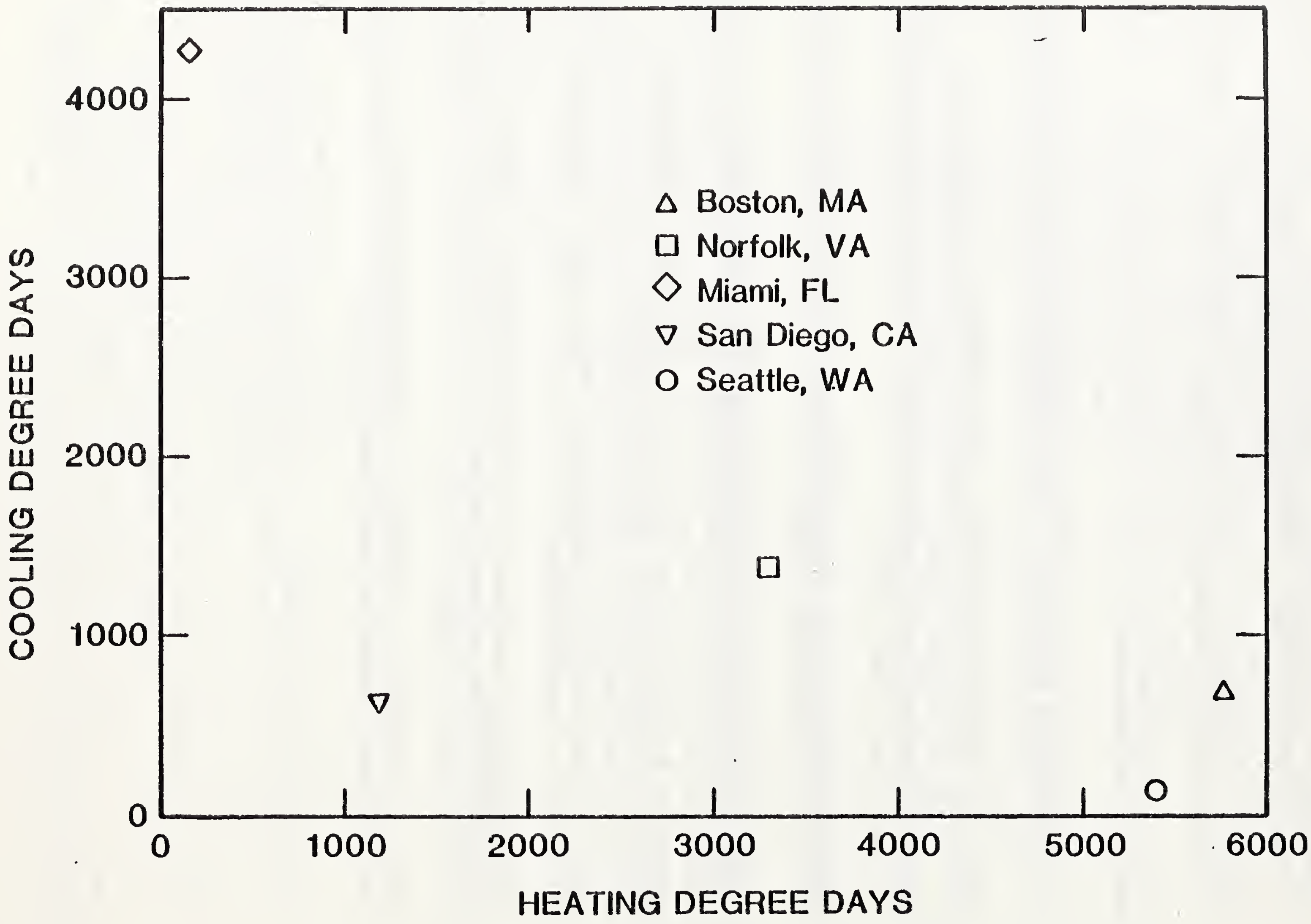



Figure 1. Heating and cooling degree days for each location

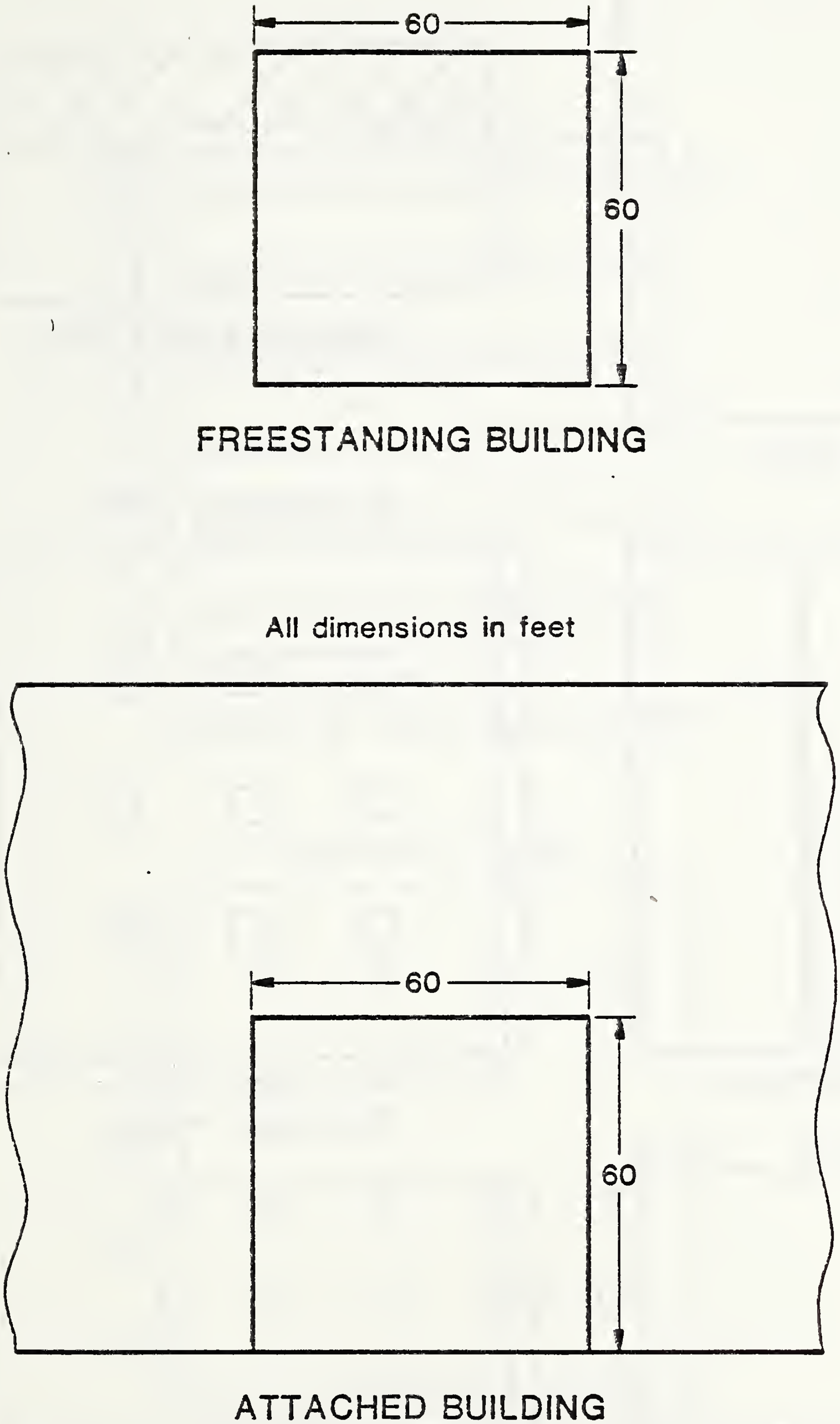



Figure 2. Schematic of floor plans for simulated building zones

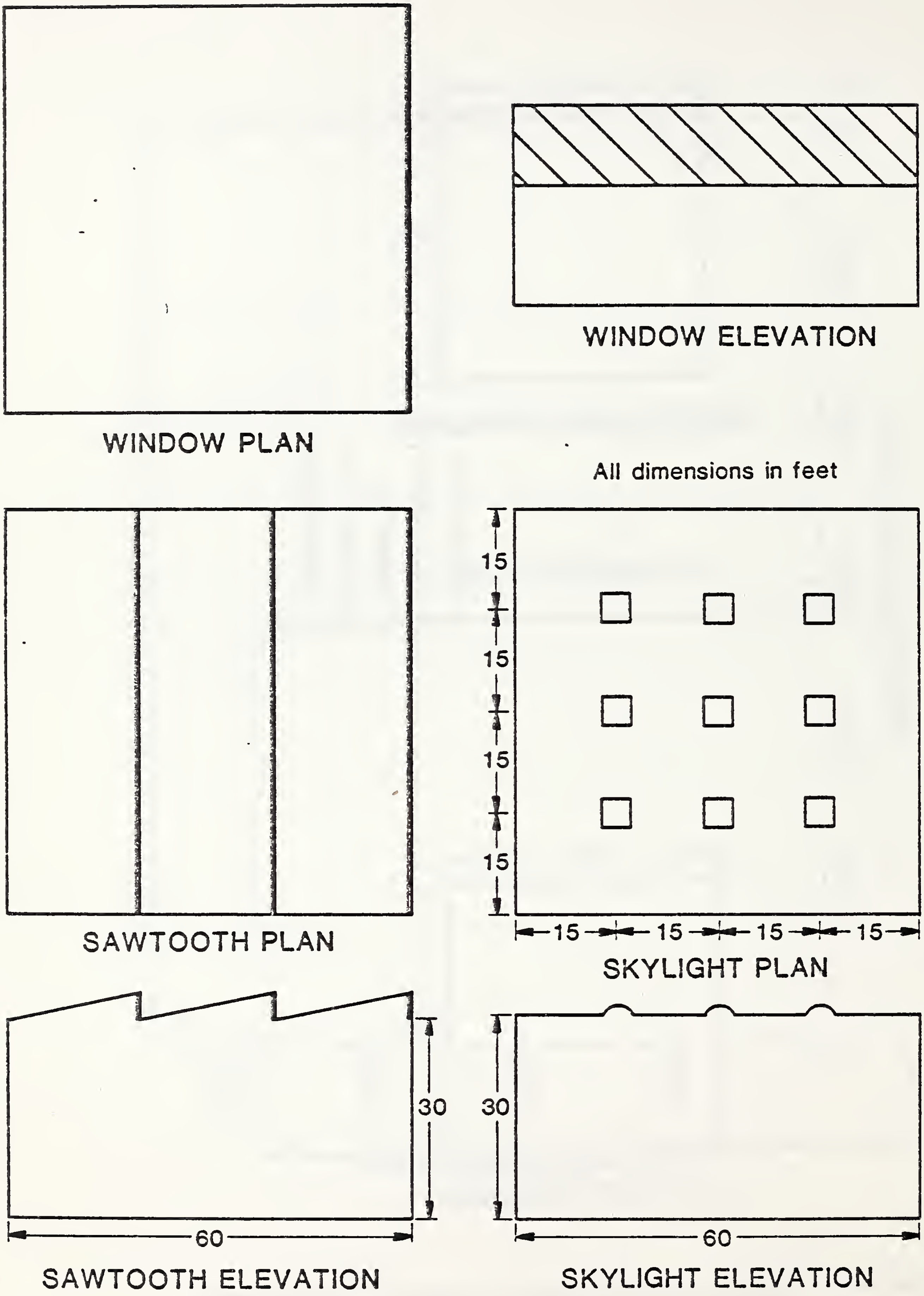



Figure 3. Schematic details of building constructions

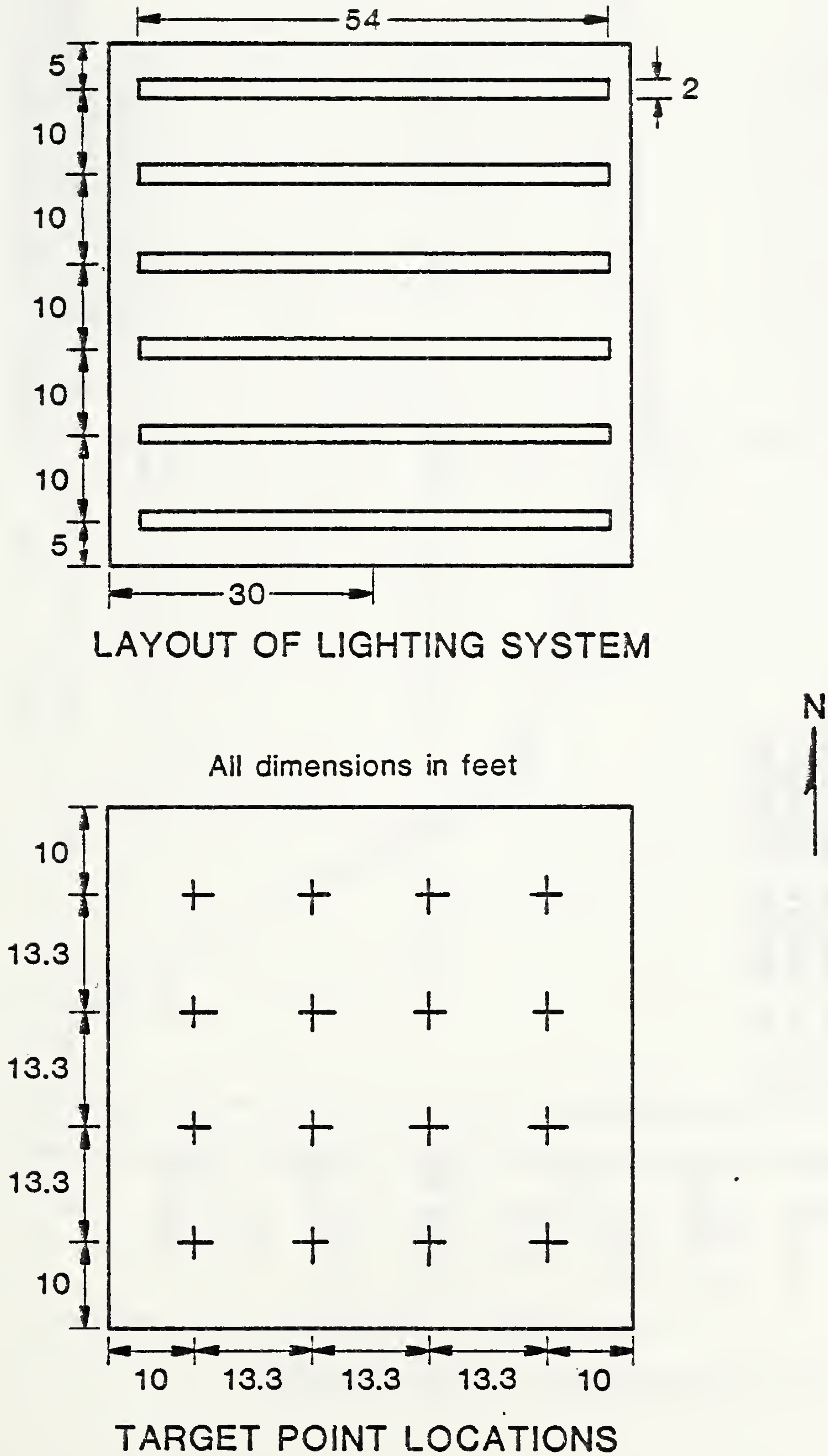



Figure 4. Layout of lighting system

Figure 5. BEST EFFECTIVE APERTURE

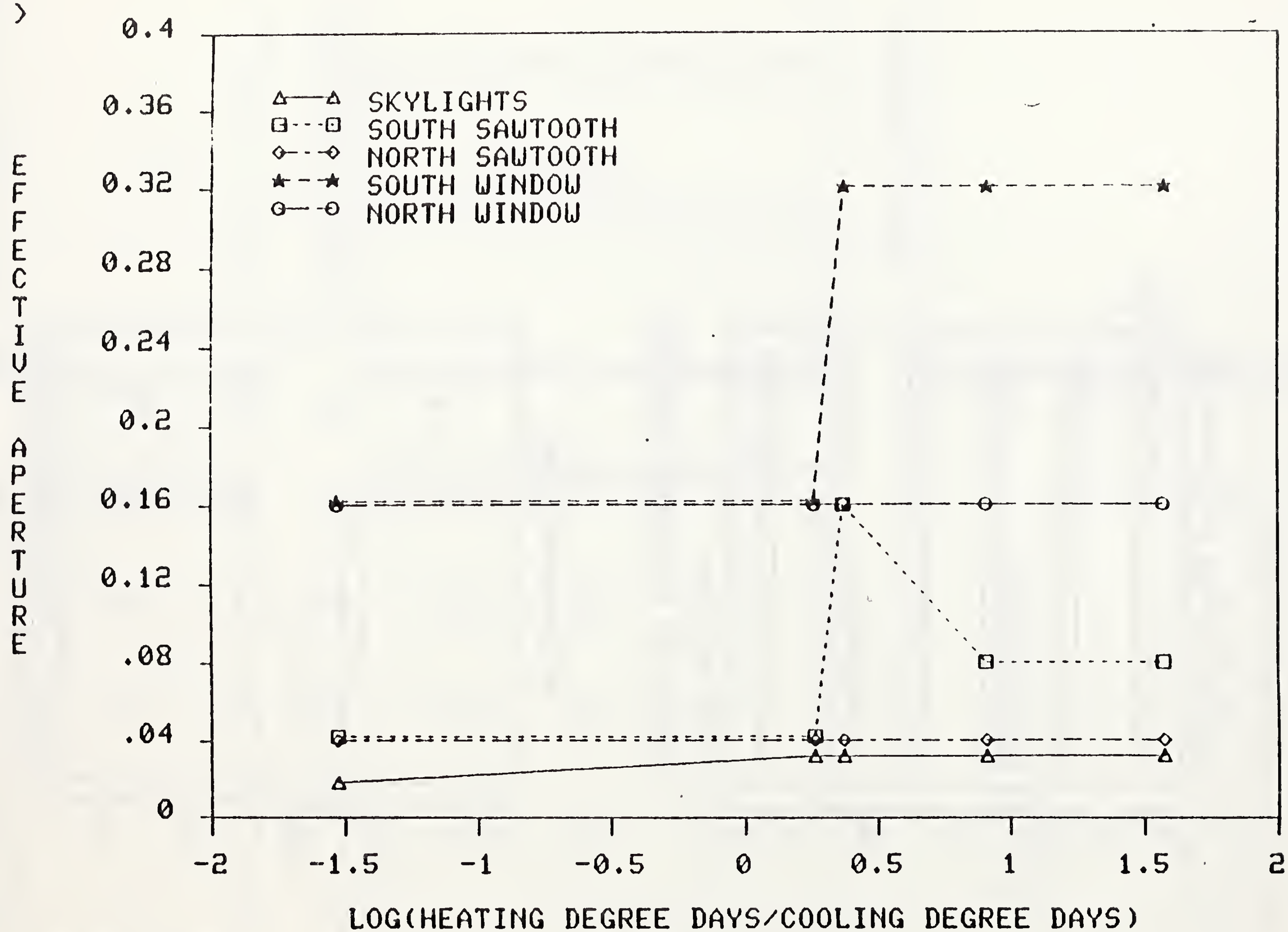


Figure 6. TOTAL ENERGY RATIO - SKYLIGHTS (Miami) WITH DAYLIGHT

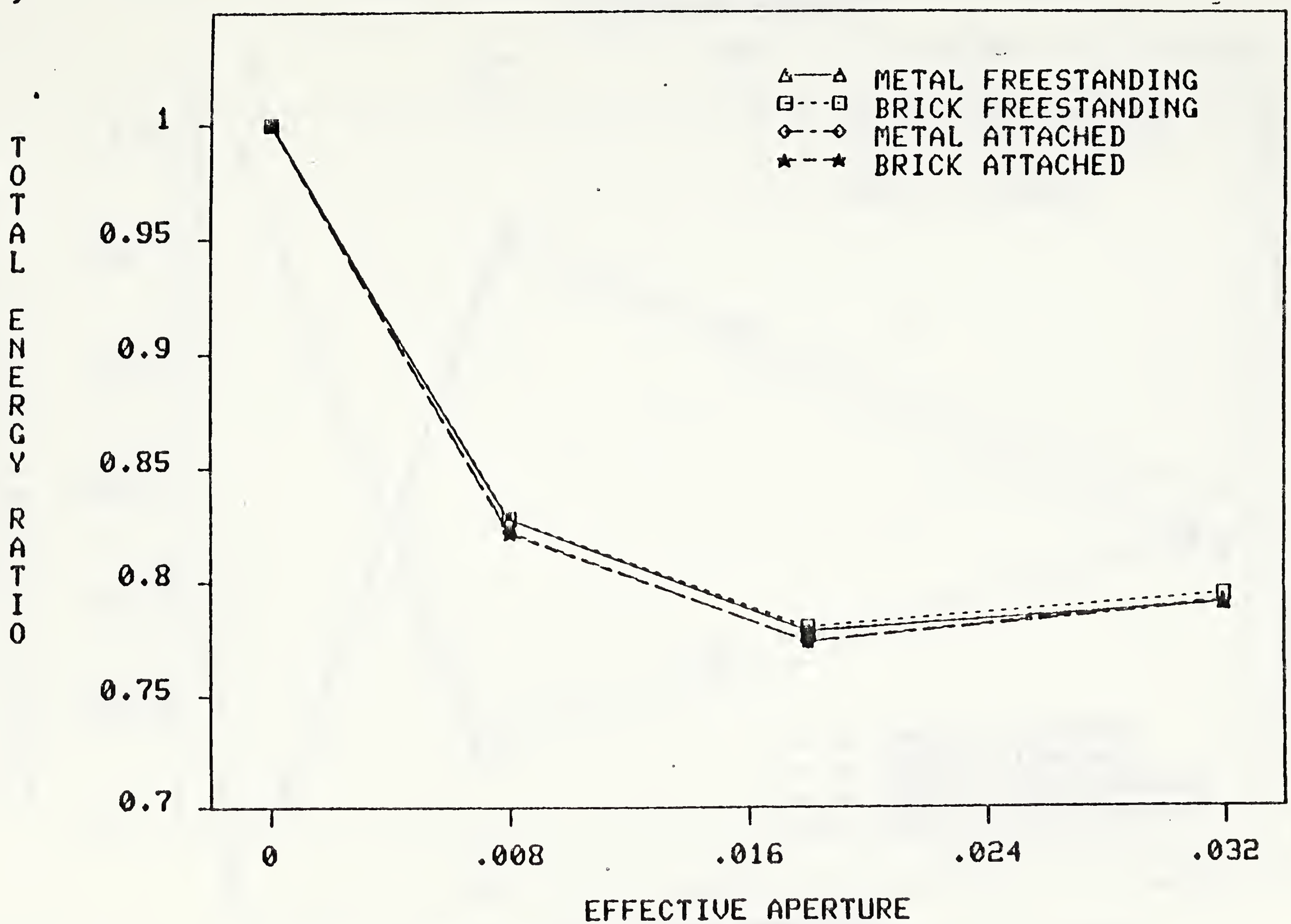


Figure 7. TOTAL ENERGY RATIO - SOUTH SAWTOOTH (Miami) WITH DAYLIGHT

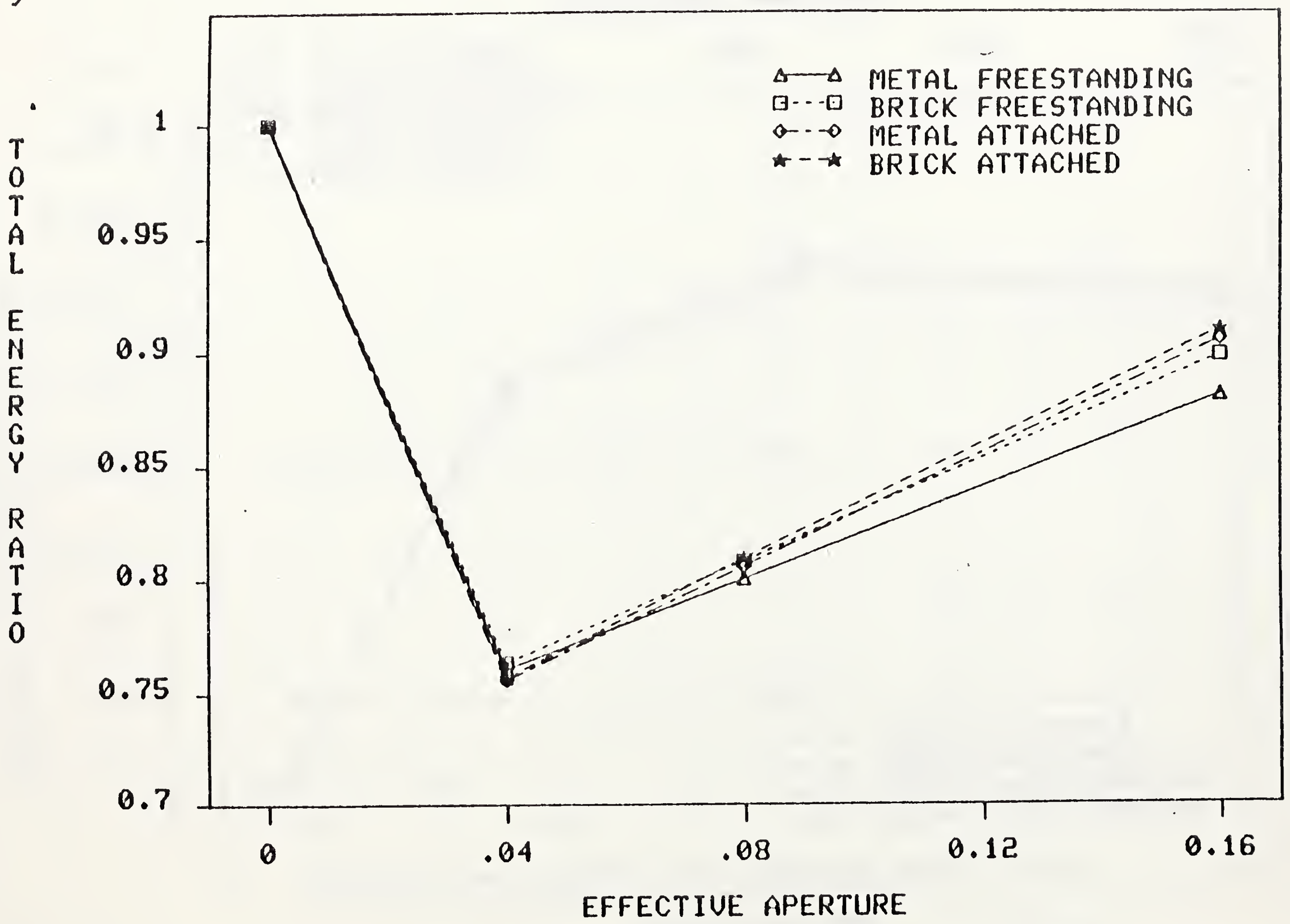


Figure 8. TOTAL ENERGY RATIO - NORTH SAWTOOTH (Miami) WITH DAYLIGHT

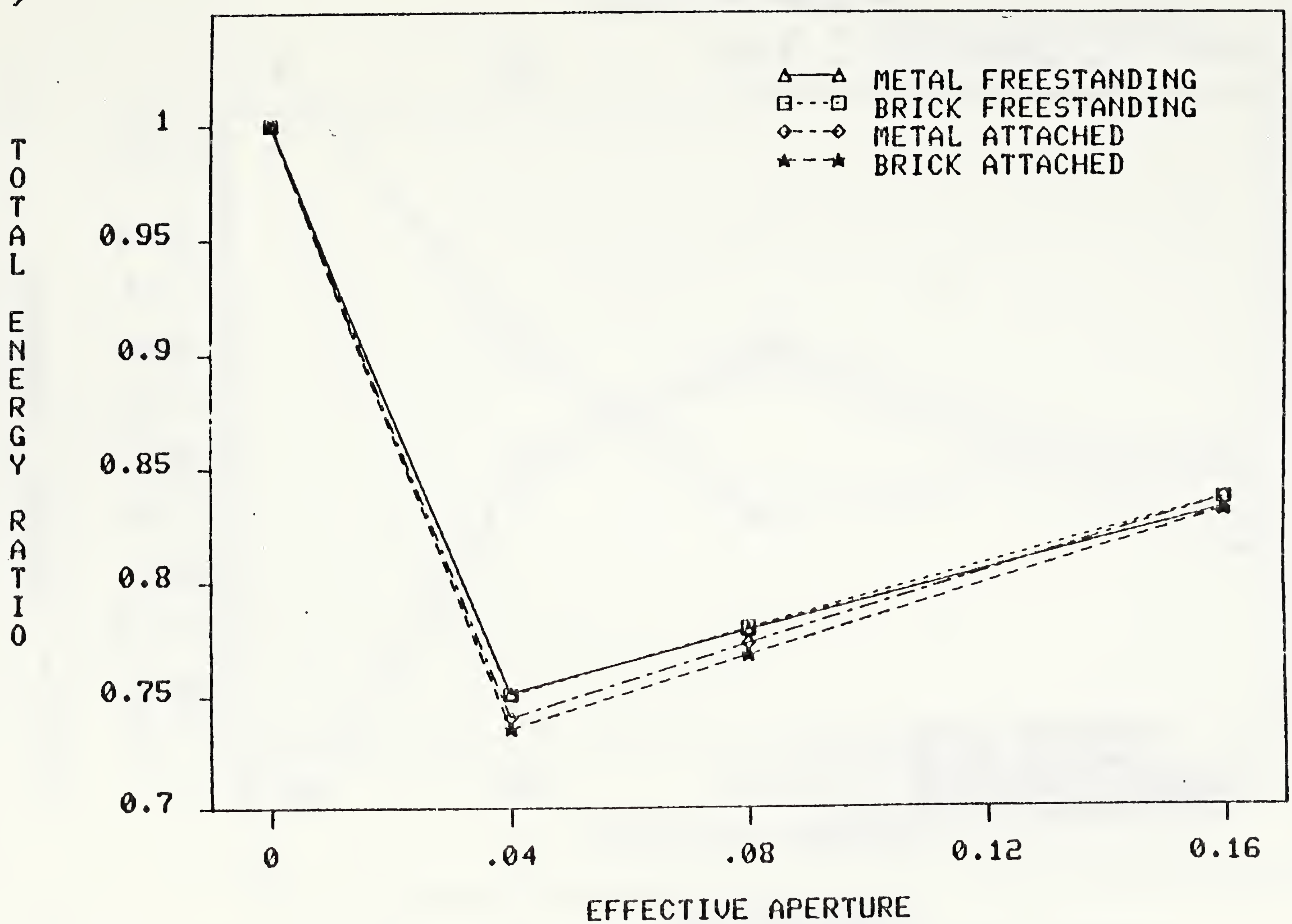


Figure 9. TOTAL ENERGY RATIO - SOUTH WINDOW (Miami) WITH DAYLIGHT

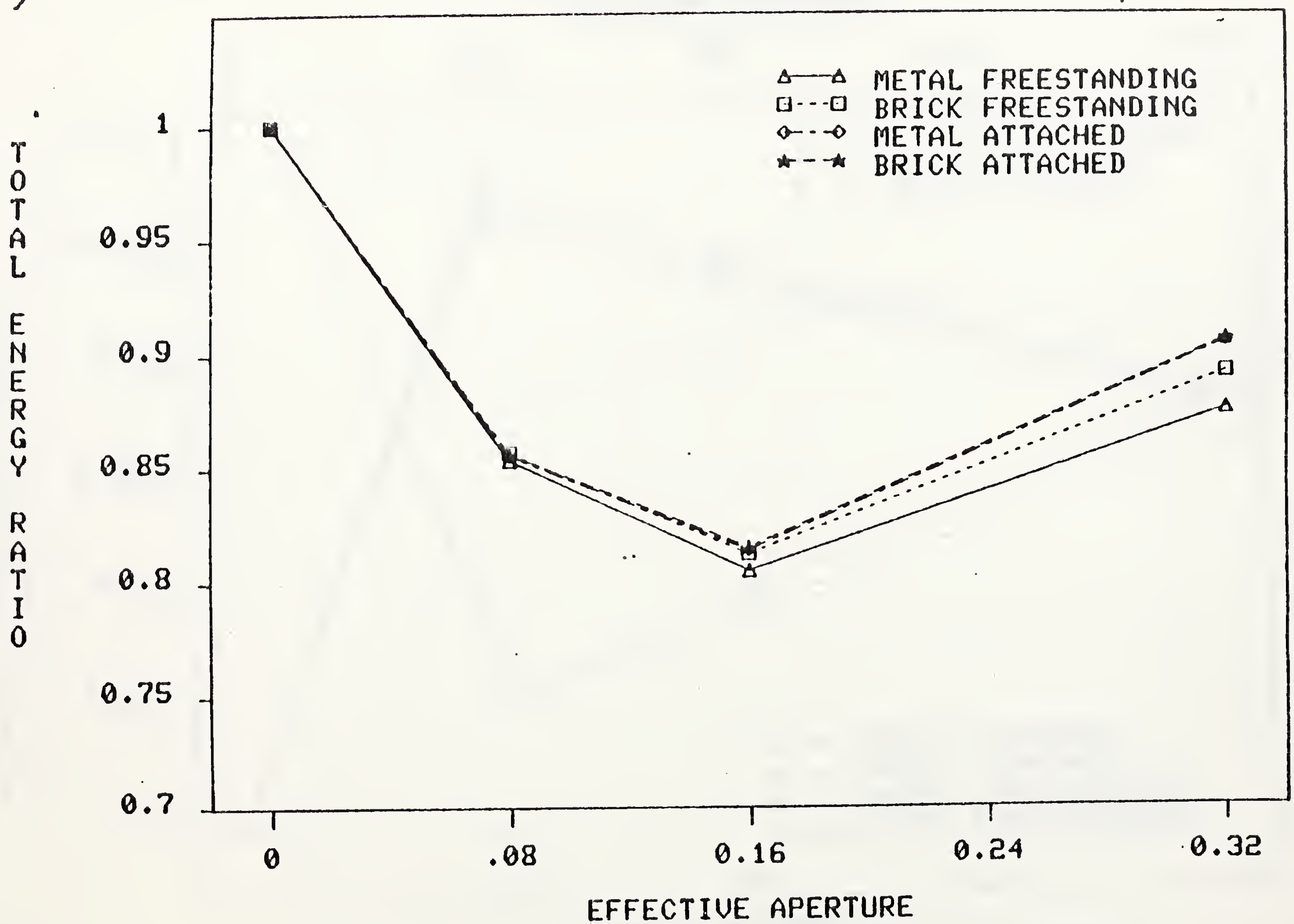


Figure 10. TOTAL ENERGY RATIO - NORTH WINDOW (Miami) WITH DAYLIGHT

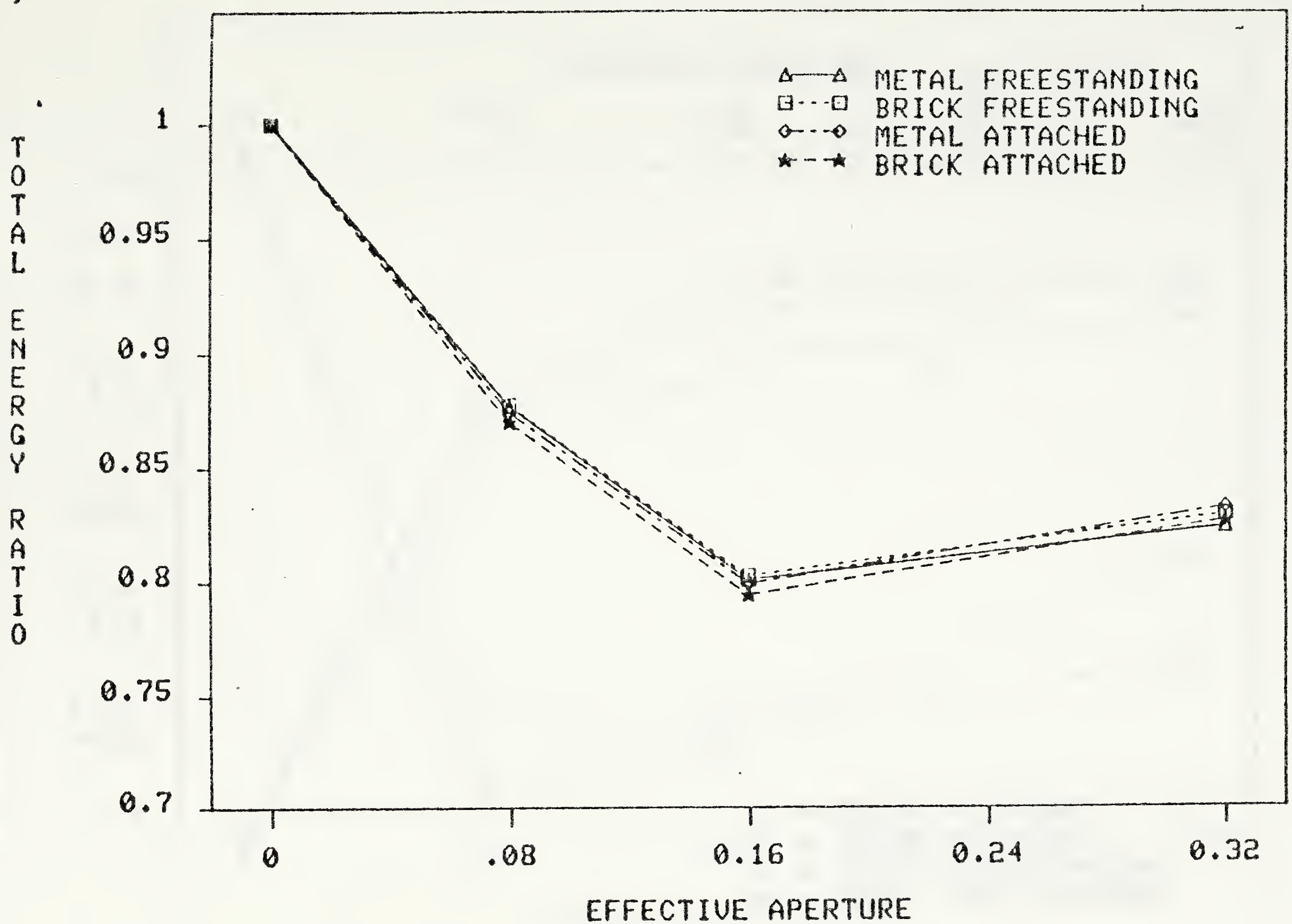


Figure 11. TOTAL ENERGY RATIO - SKYLIGHTS (San Diego) WITH DAYLIGHT

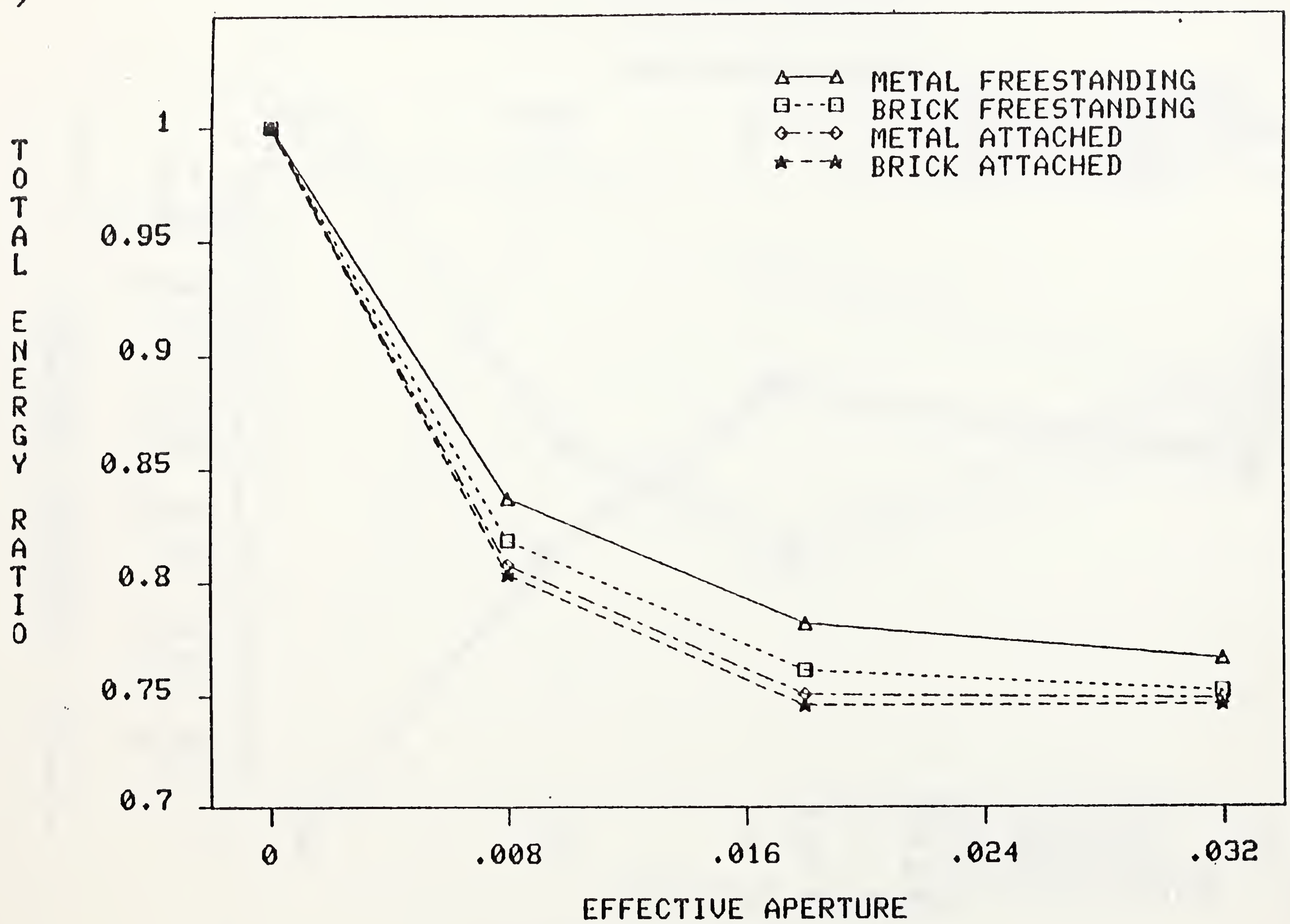


Figure 12. TOTAL ENERGY RATIO - SOUTH SAWTOOTH (San Diego) WITH DAYLIGHT

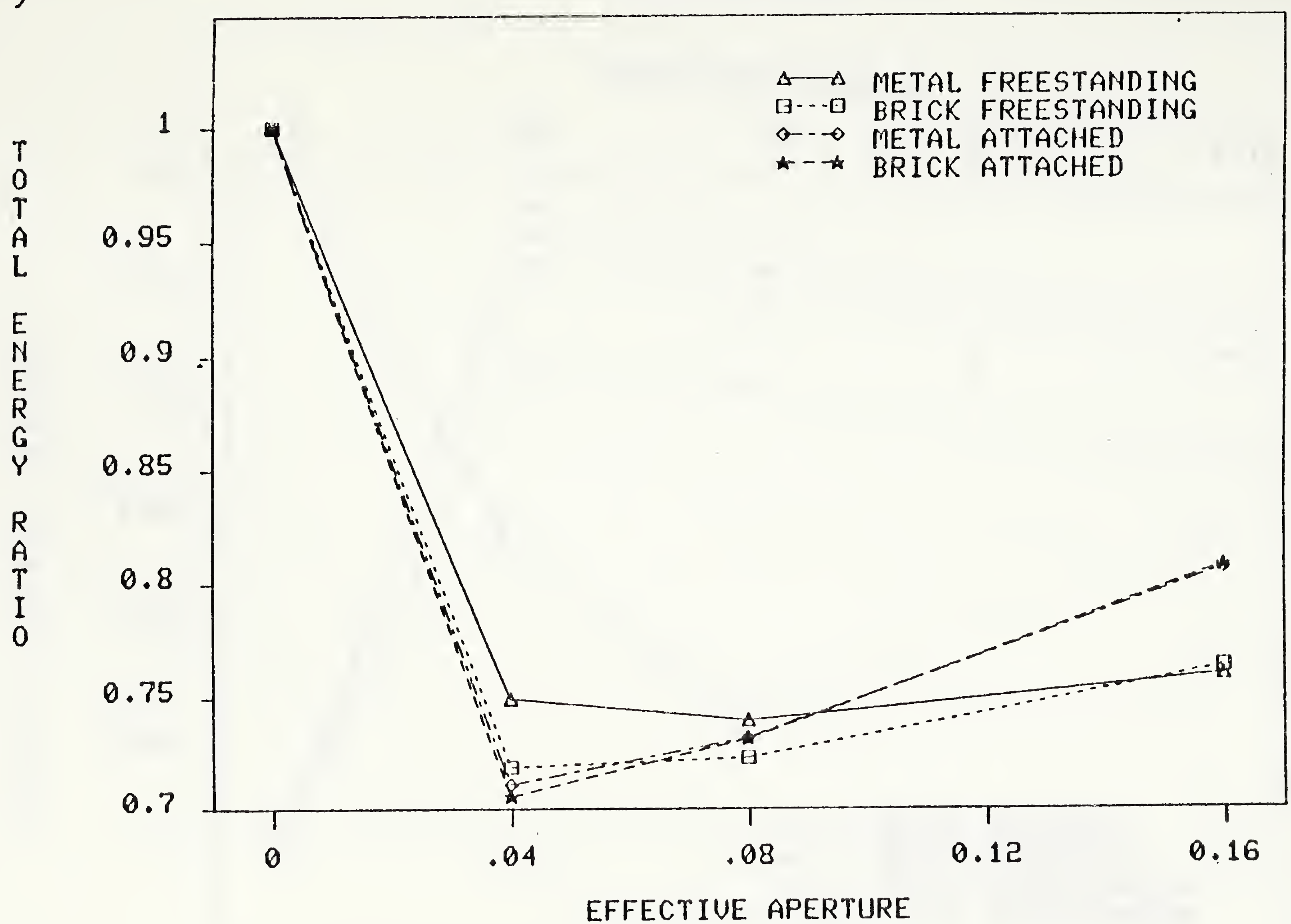


Figure 13. TOTAL ENERGY RATIO - NORTH SAWTOOTH (San Diego) WITH DAYLIGHT

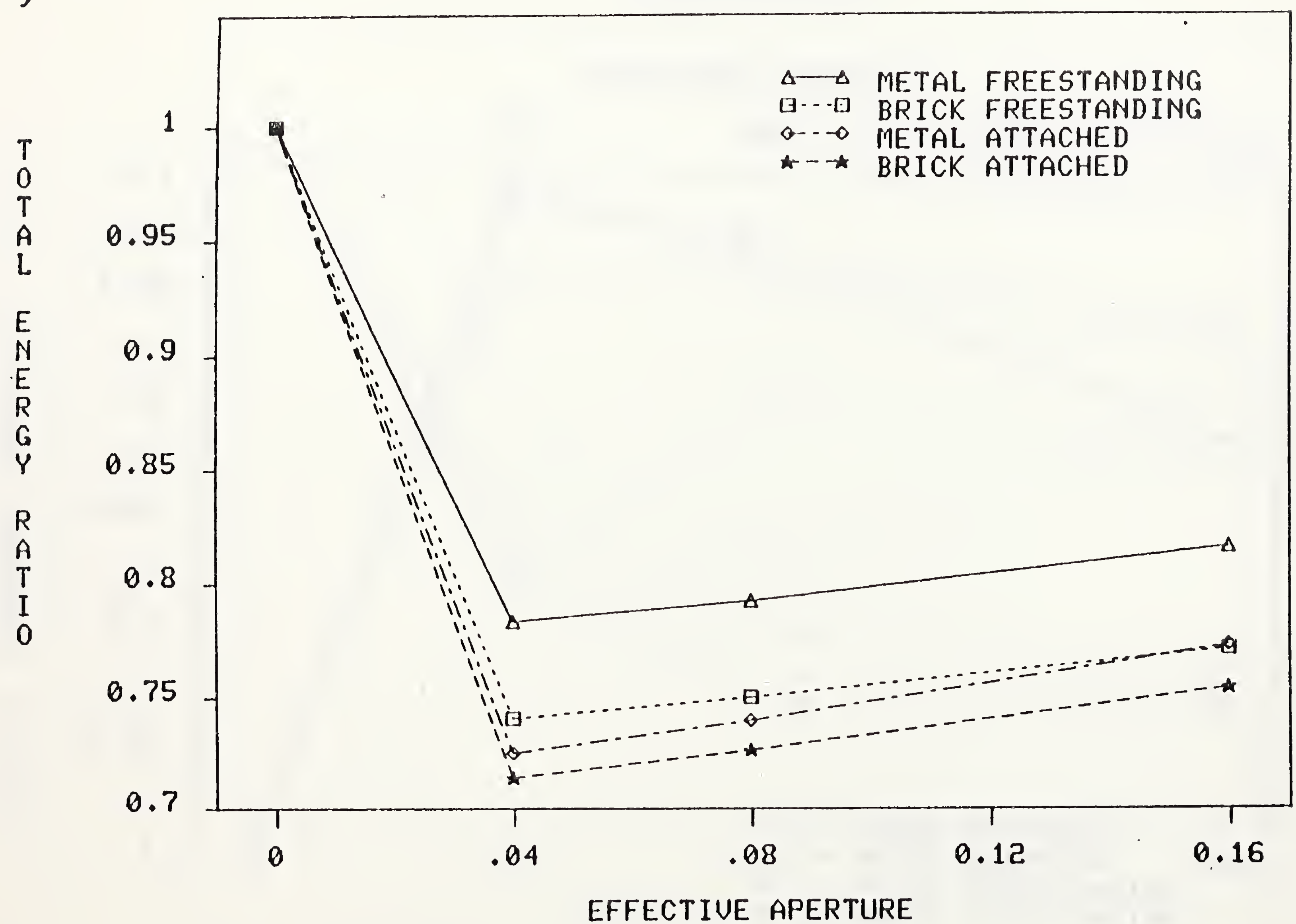


Figure 14. TOTAL ENERGY RATIO - SOUTH WINDOW (San Diego) WITH DAYLIGHT

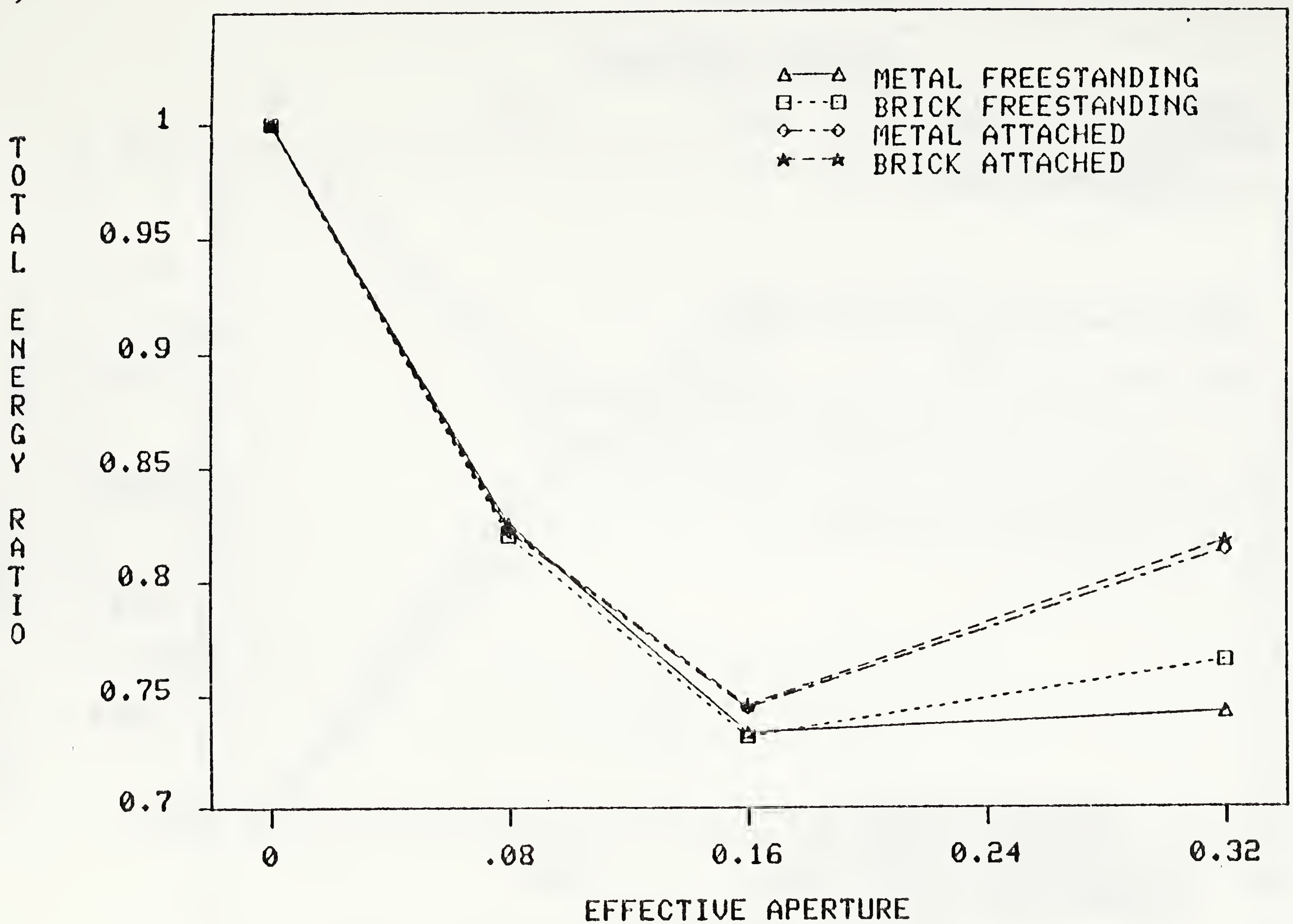


Figure 15. TOTAL ENERGY RATIO - NORTH WINDOW (San Diego) WITH DAYLIGHT

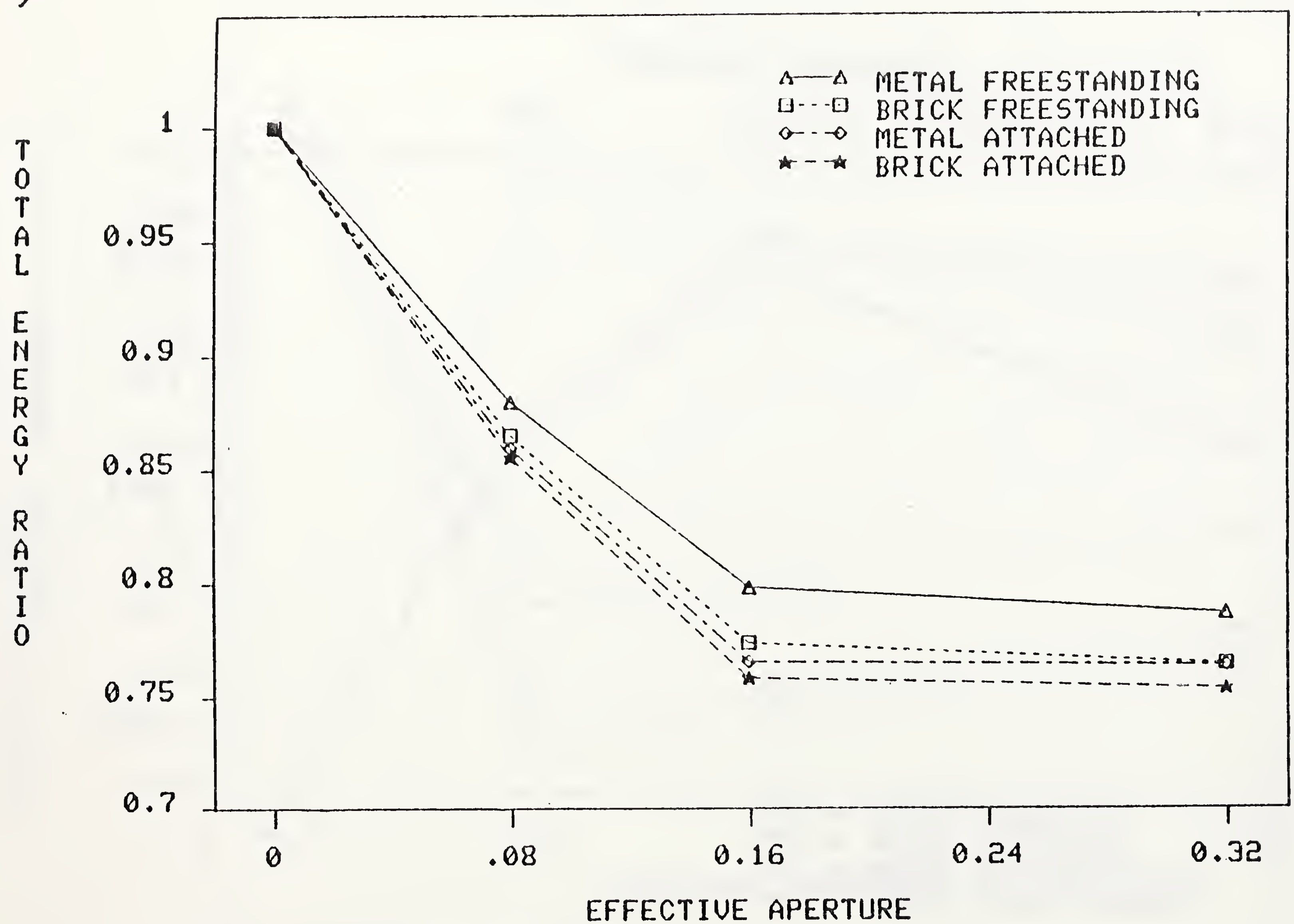


Figure 16. TOTAL ENERGY RATIO - SKYLIGHTS (Norfolk) WITH DAYLIGHT

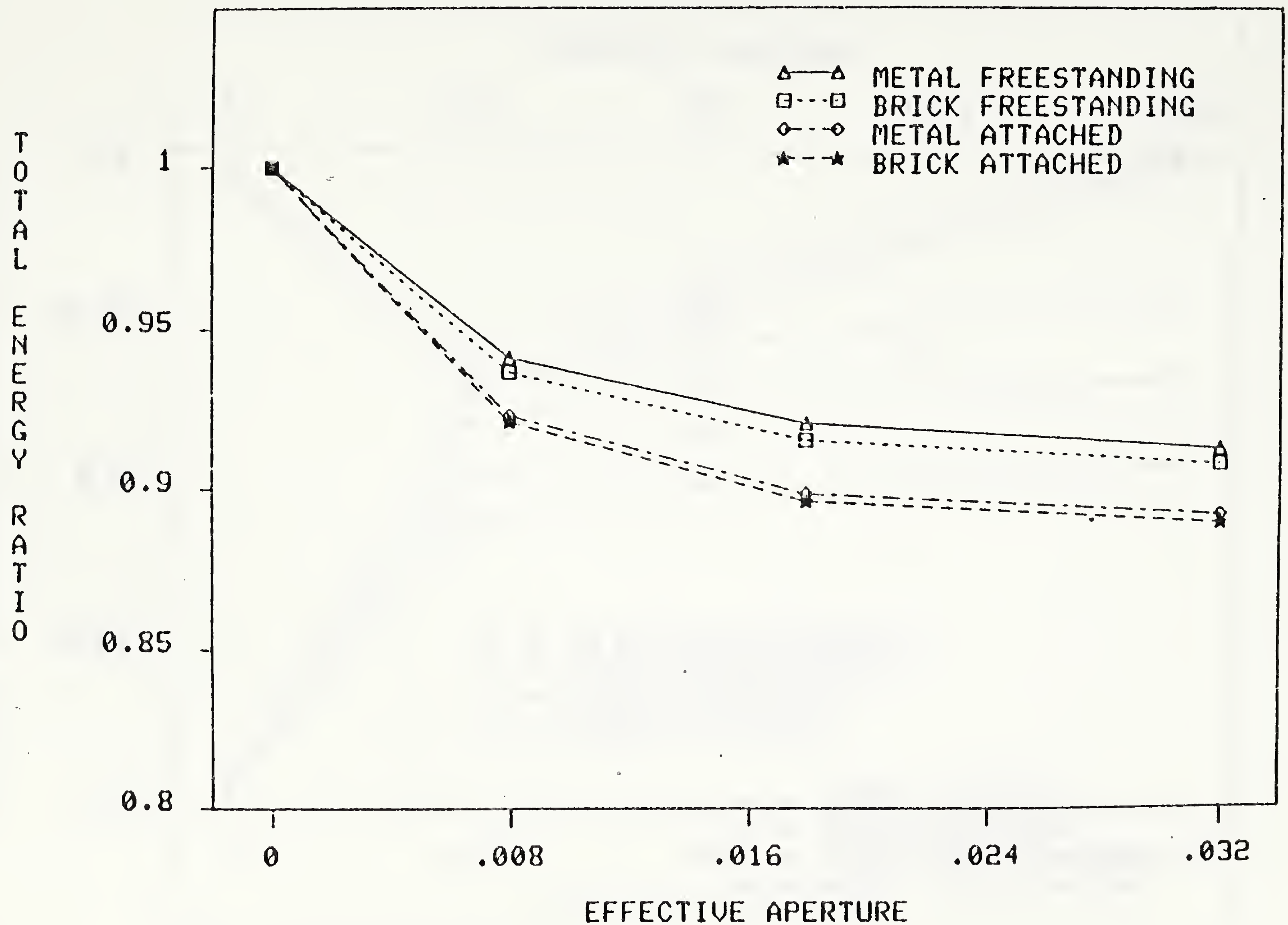


Figure 17. TOTAL ENERGY RATIO - SOUTH SAWTOOTH (Norfolk) WITH DAYLIGHT

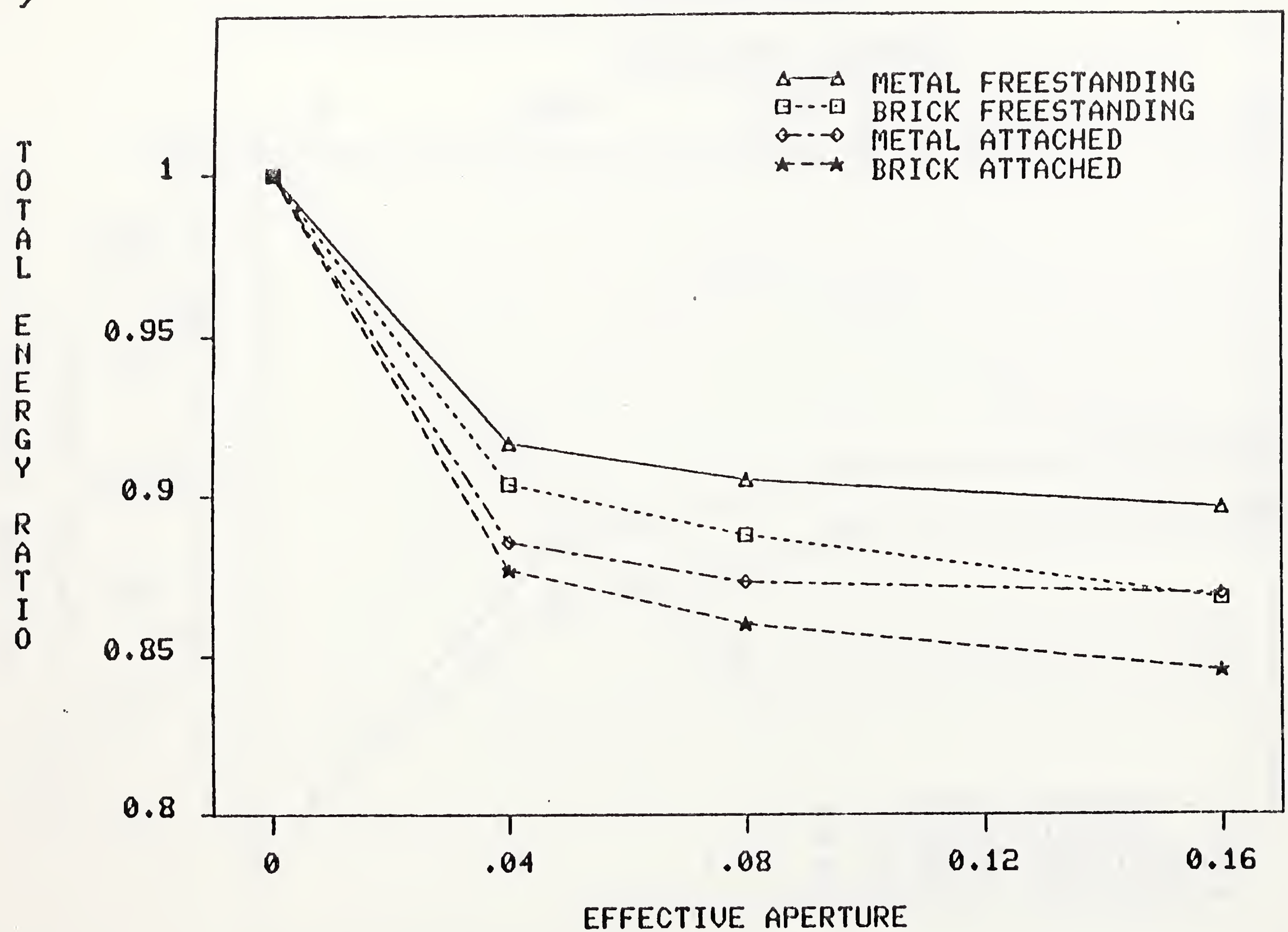


Figure 18. TOTAL ENERGY RATIO - NORTH SAWTOOTH (Norfolk) WITH DAYLIGHT

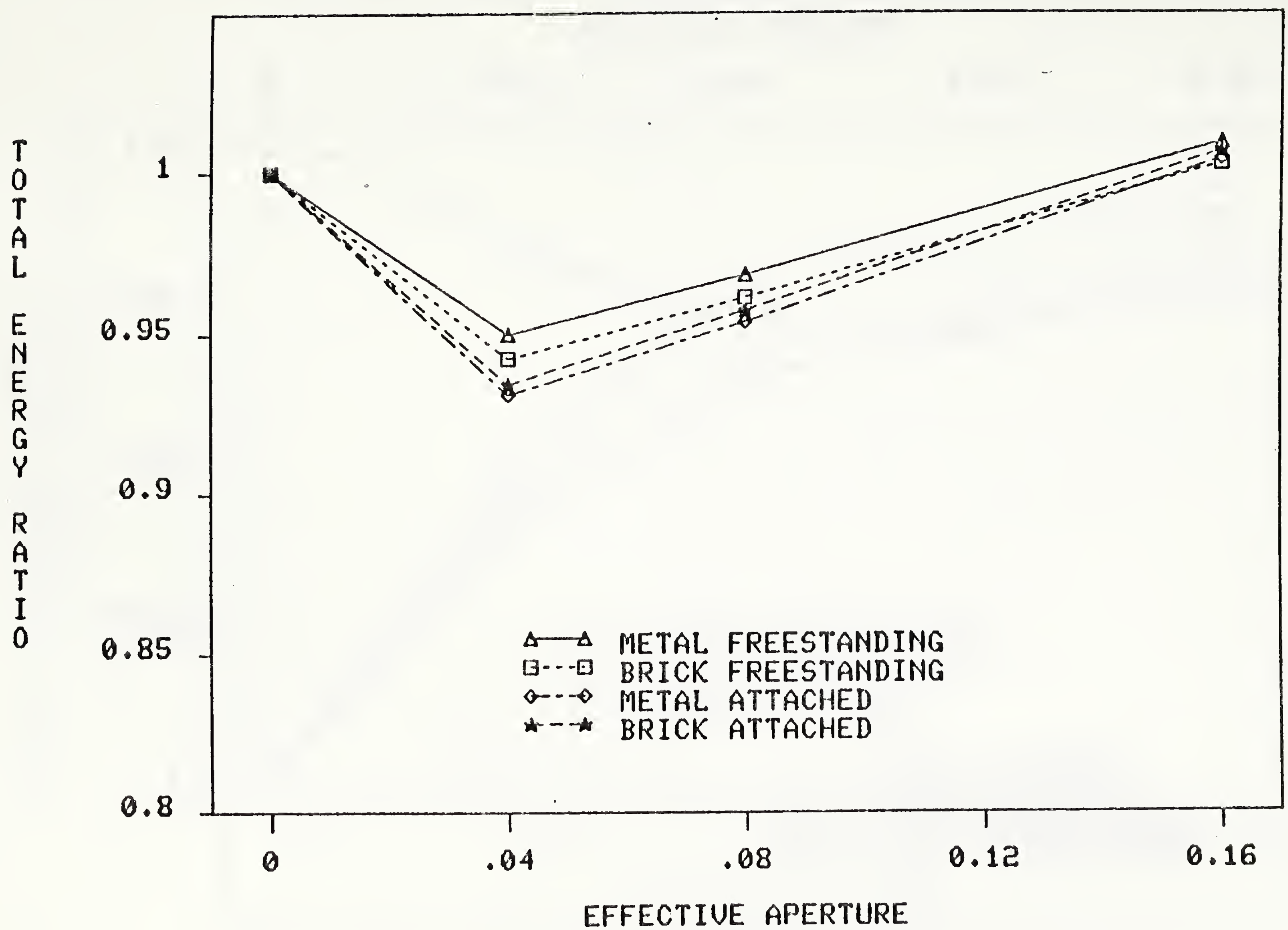


Figure 19. TOTAL ENERGY RATIO - SOUTH WINDOW (Norfolk) WITH DAYLIGHT

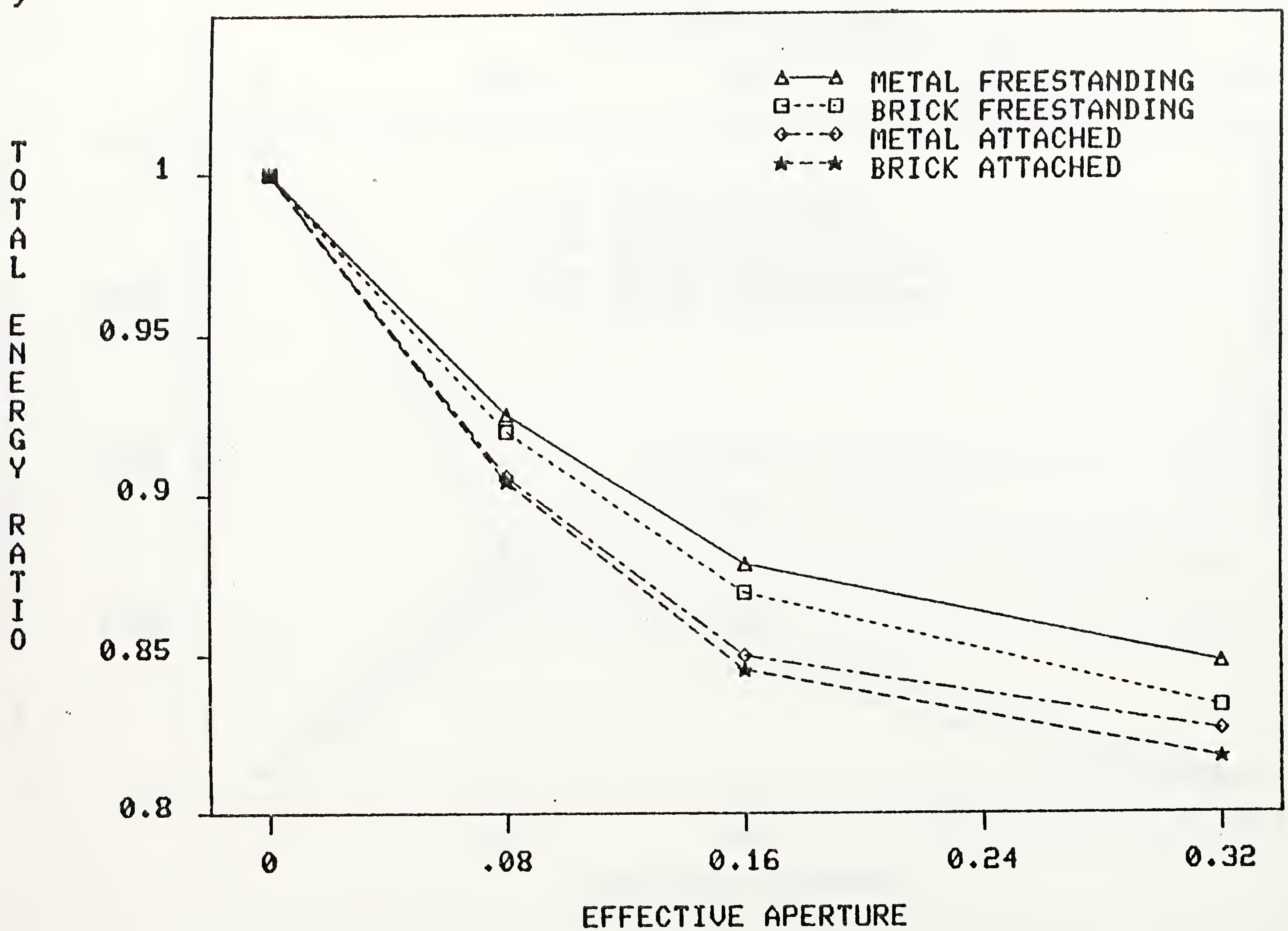


Figure 20. TOTAL ENERGY RATIO - NORTH WINDOW (Norfolk) WITH DAYLIGHT

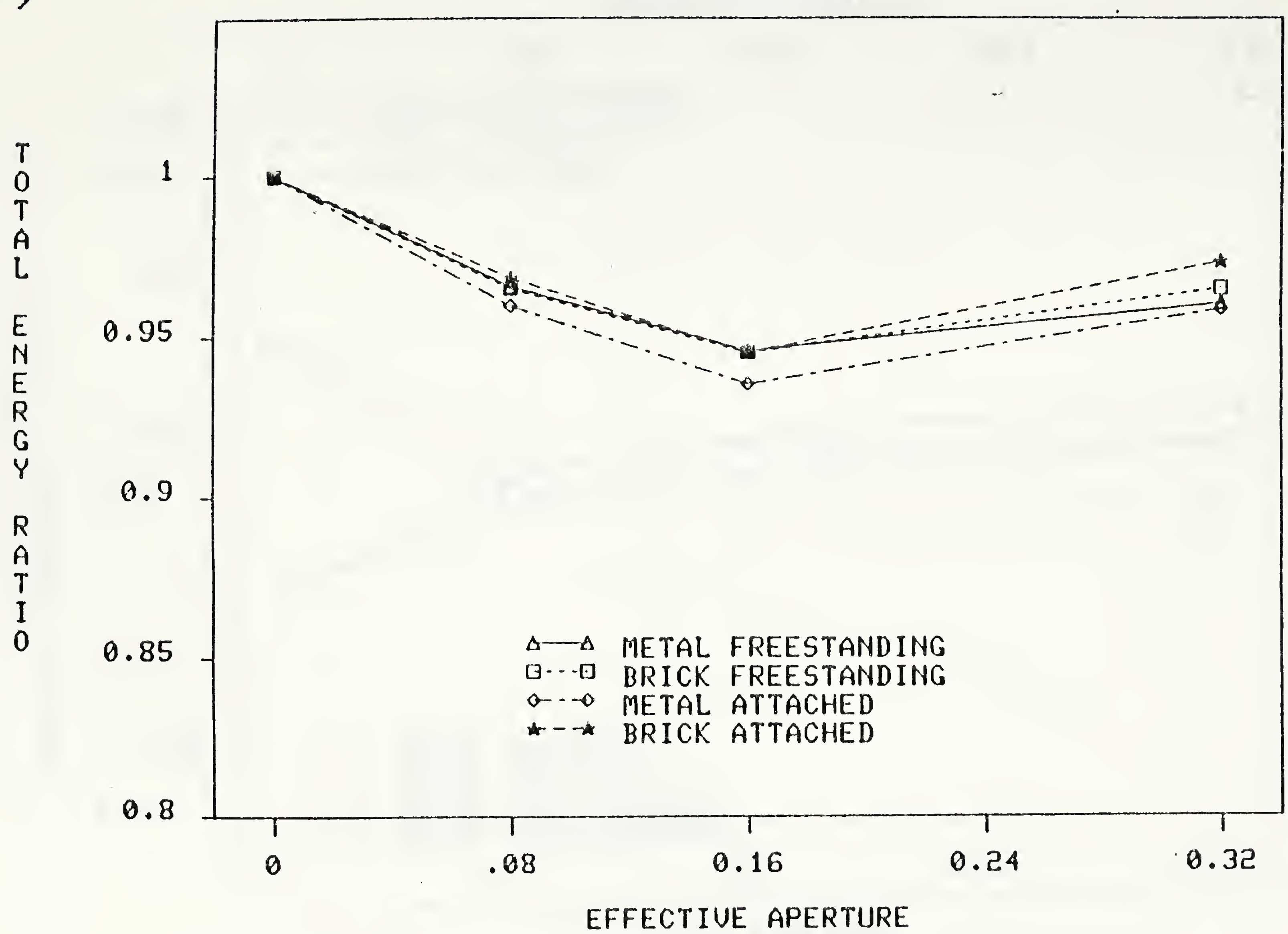


Figure 21. TOTAL ENERGY RATIO - SKYLIGHTS (Boston) WITH DAYLIGHT

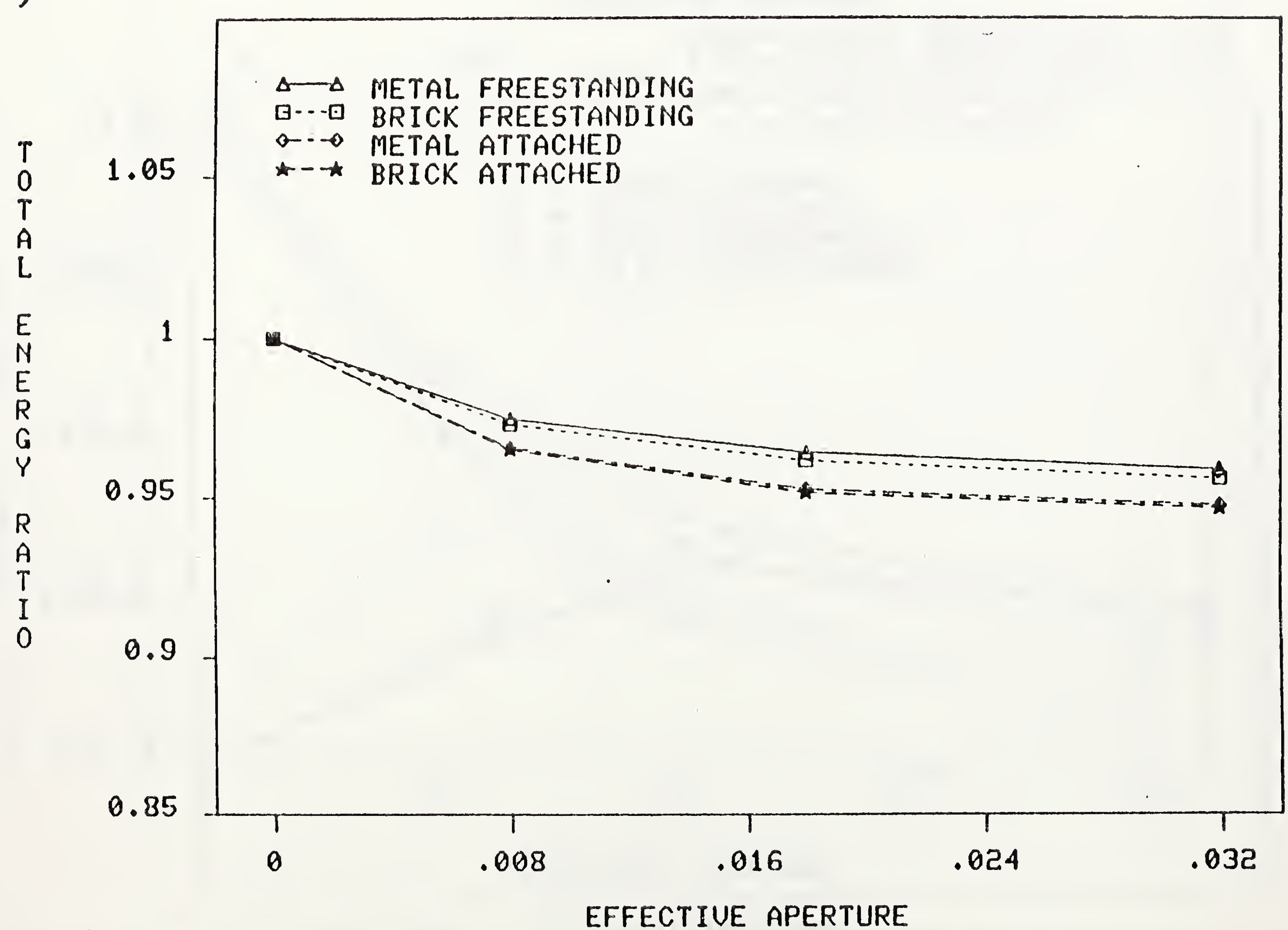


Figure 22. TOTAL ENERGY RATIO - SOUTH SAWTOOTH (Boston) WITH DAYLIGHT

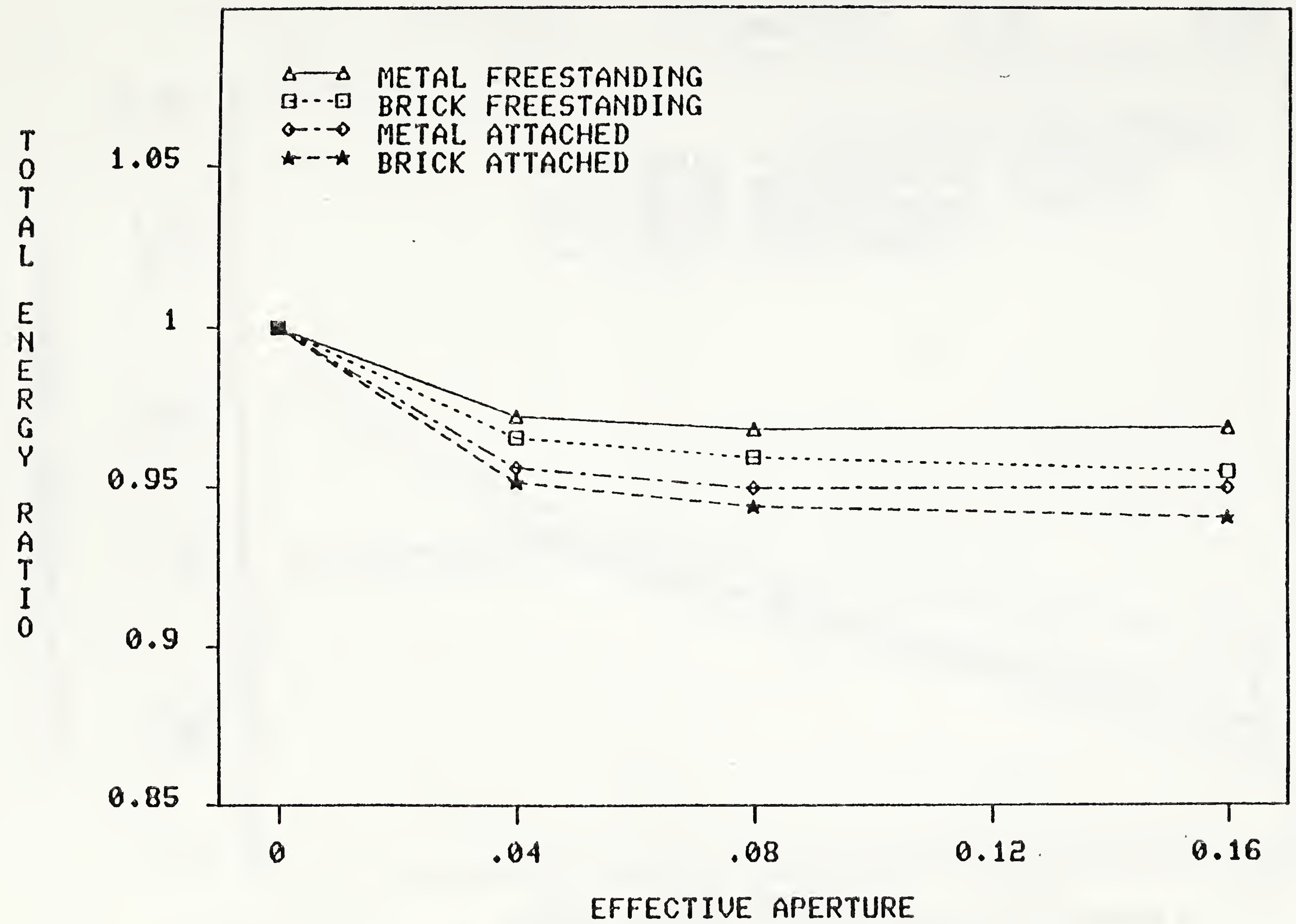


Figure 23. TOTAL ENERGY RATIO - NORTH SAWTOOTH (Boston) WITH DAYLIGHT

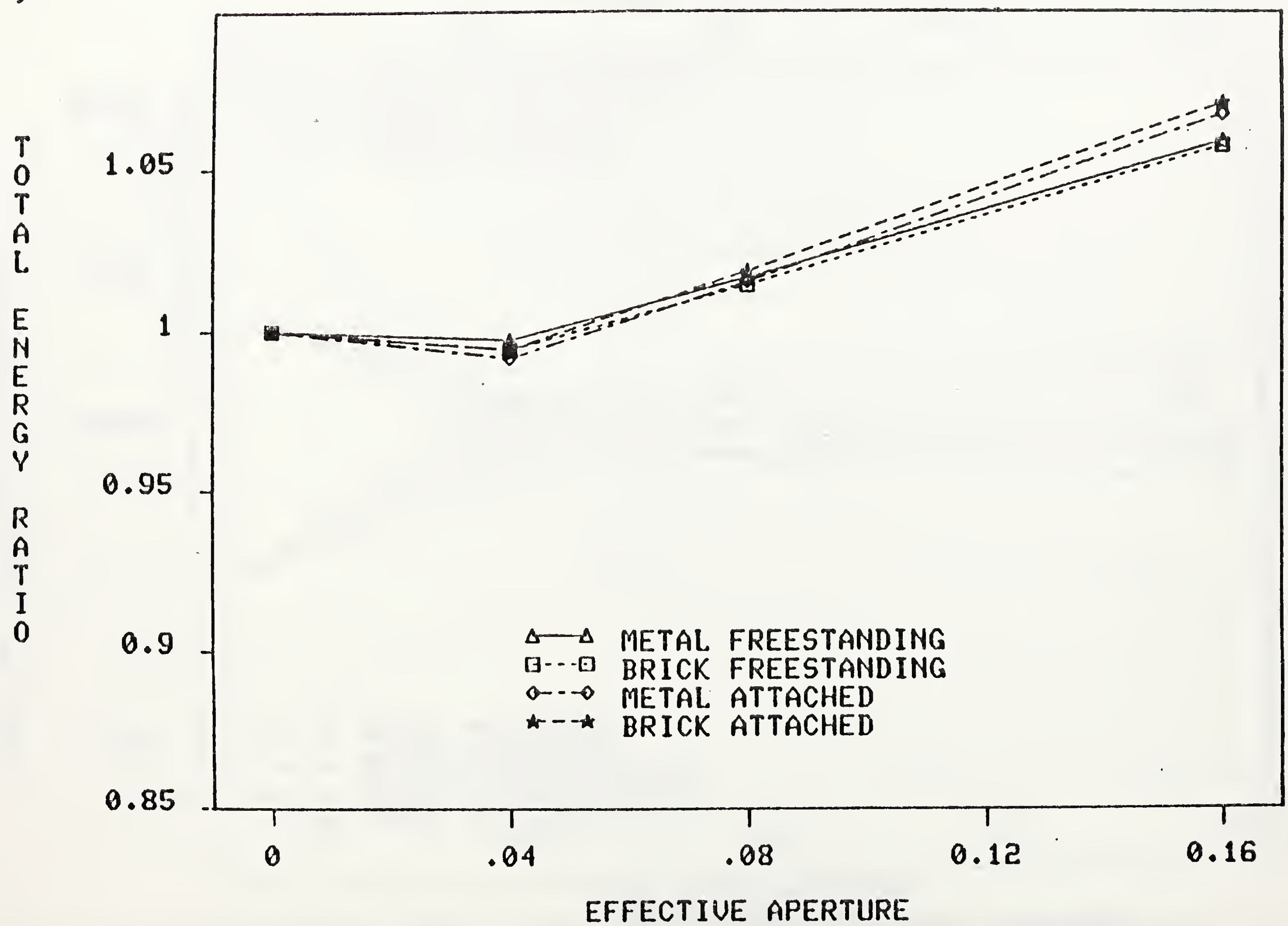


Figure 24. TOTAL ENERGY RATIO - SOUTH WINDOW (Boston) WITH DAYLIGHT

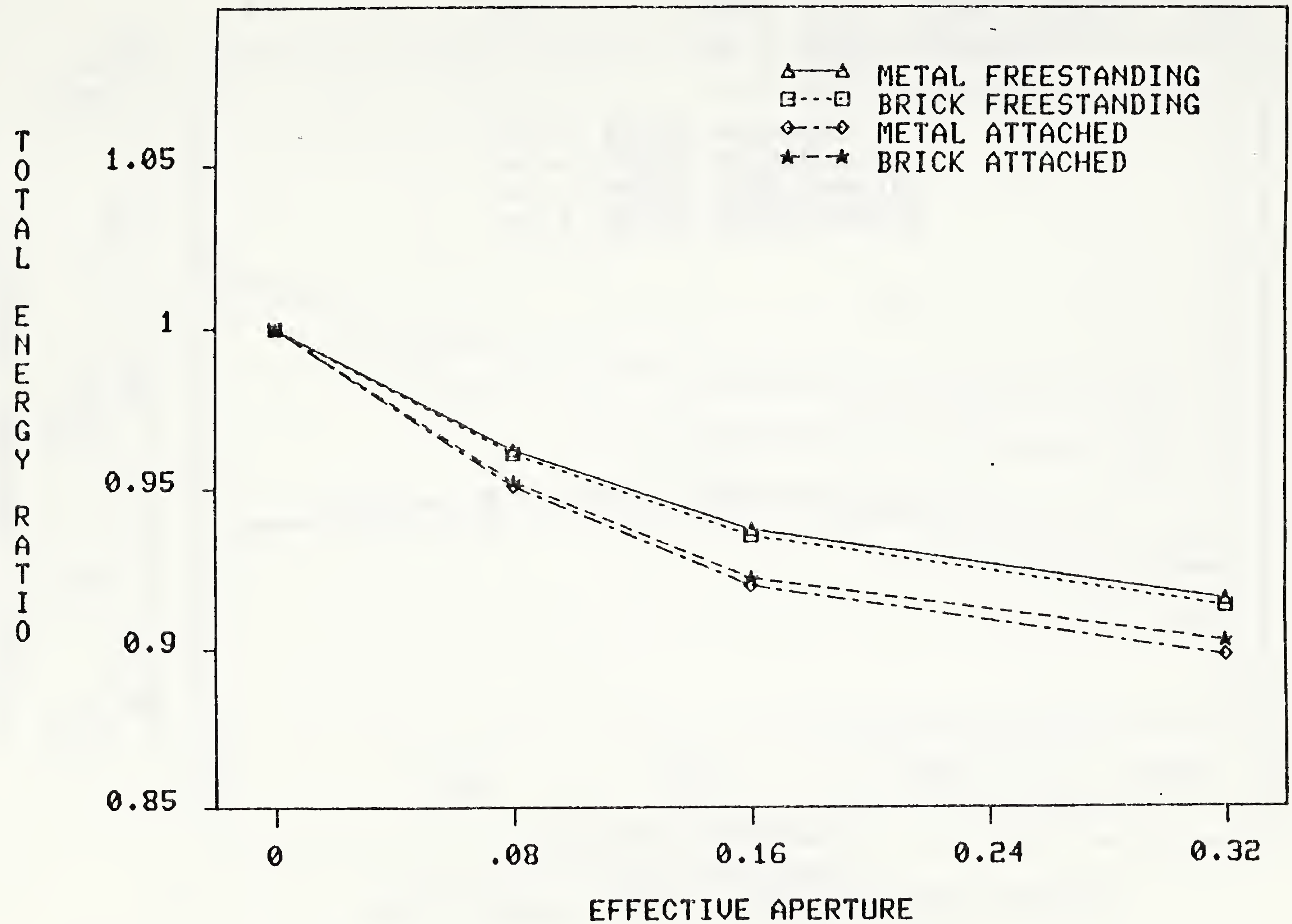


Figure 25. TOTAL ENERGY RATIO - NORTH WINDOW (Boston) WITH DAYLIGHT

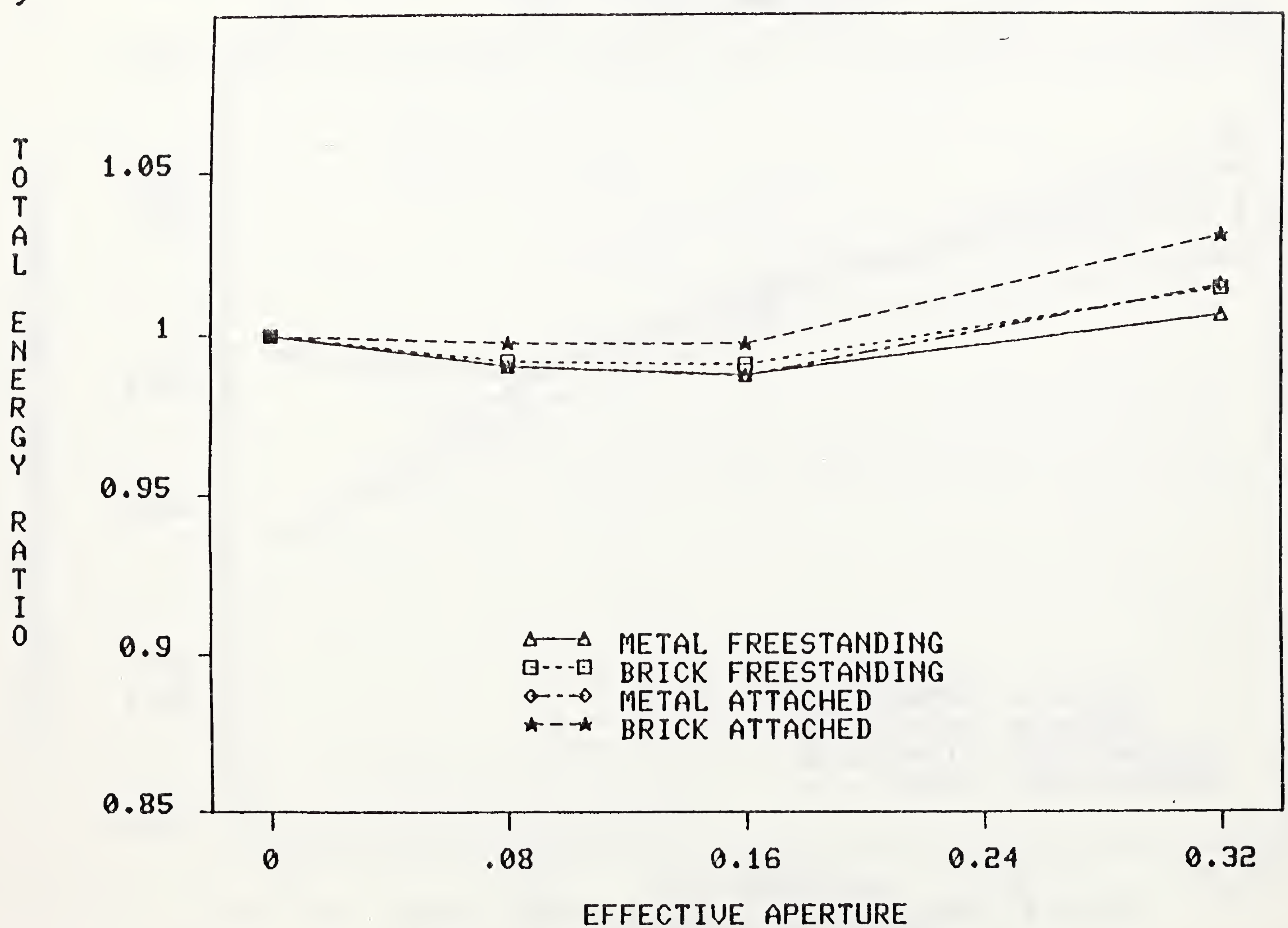


Figure 26. TOTAL ENERGY RATIO - SKYLIGHTS (Seattle) WITH DAYLIGHT

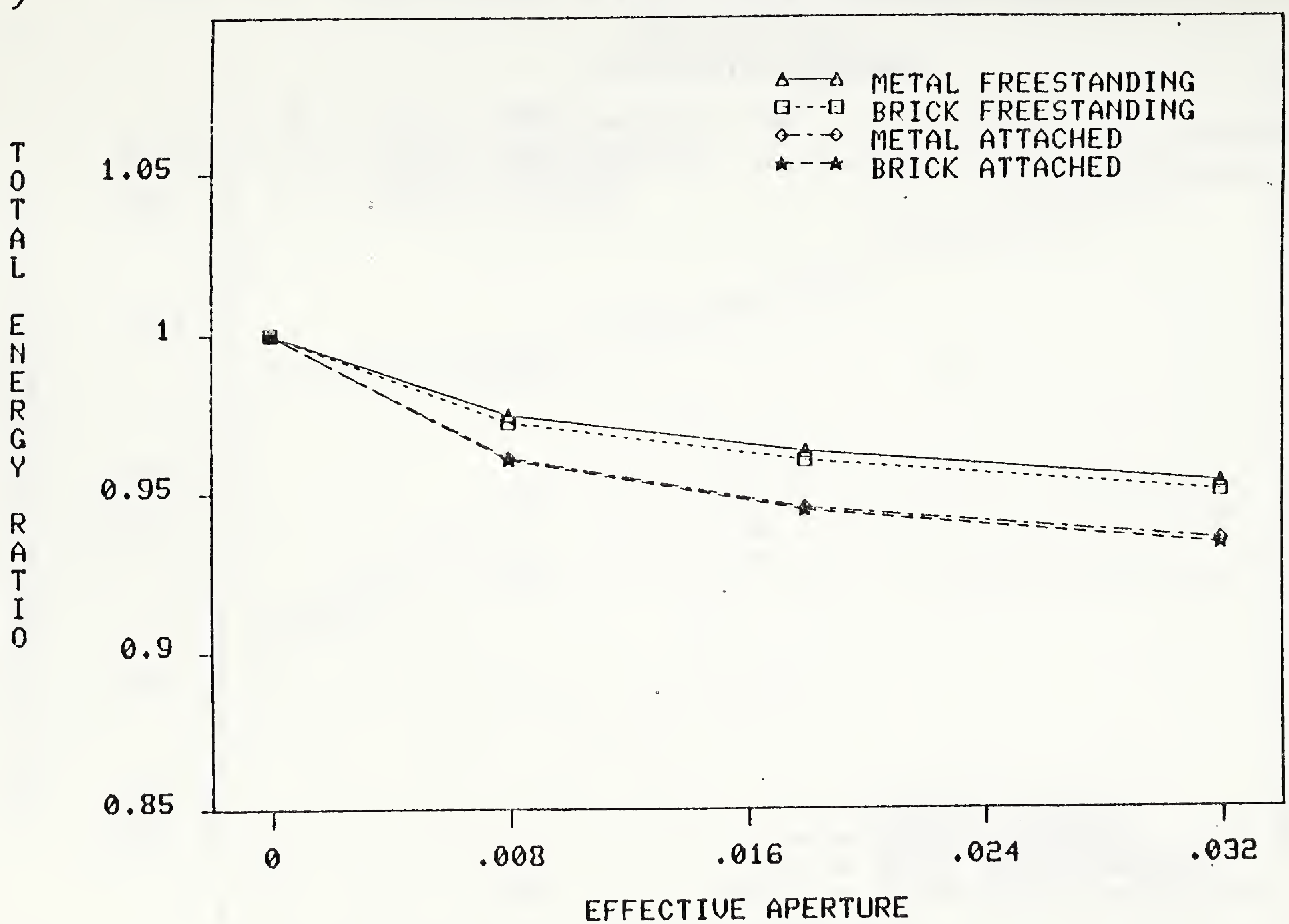


Figure 27. TOTAL ENERGY RATIO - SOUTH SAWTOOTH (Seattle) WITH DAYLIGHT

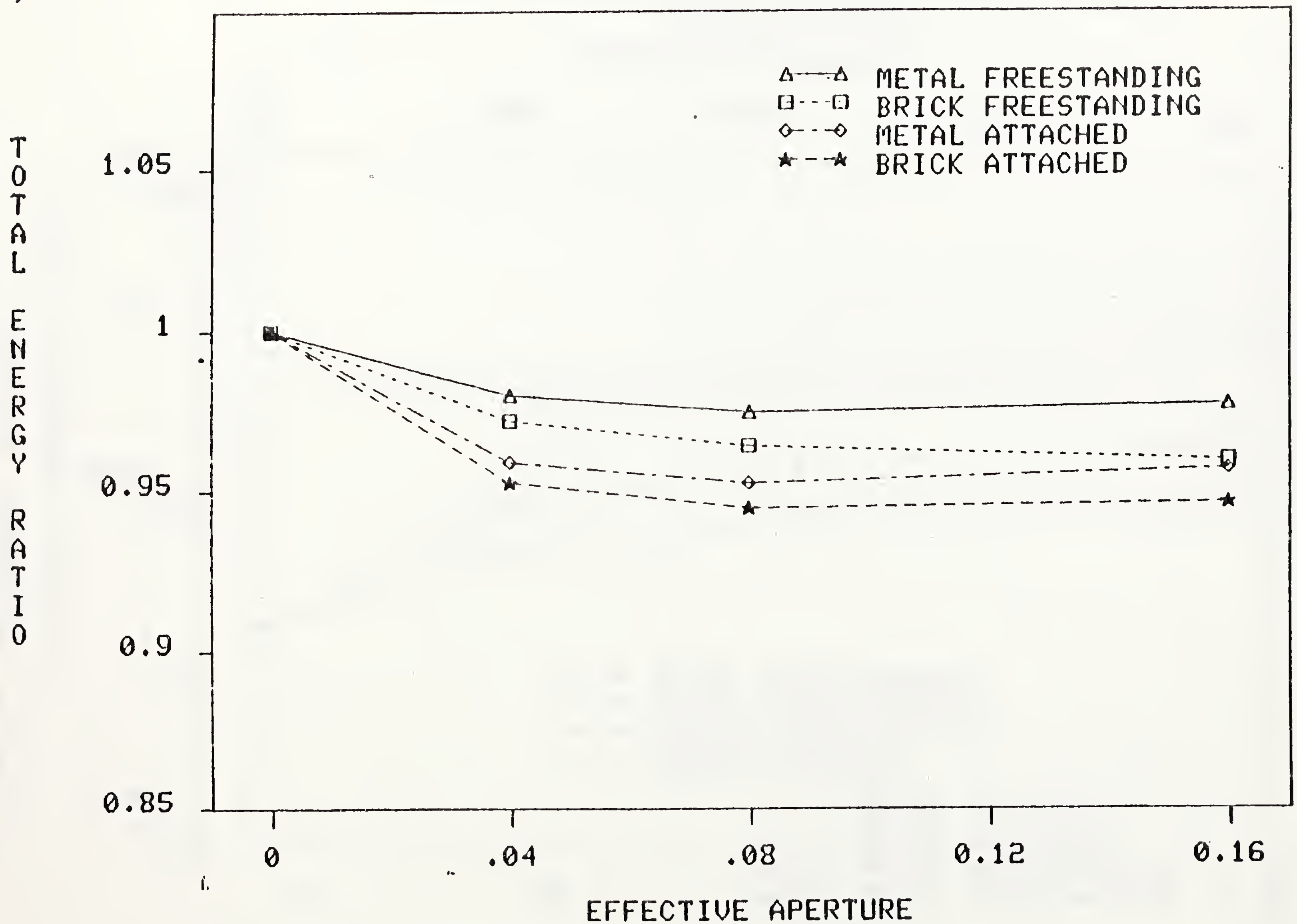


Figure 28. TOTAL ENERGY RATIO - NORTH SAWTOOTH (Seattle) WITH DAYLIGHT

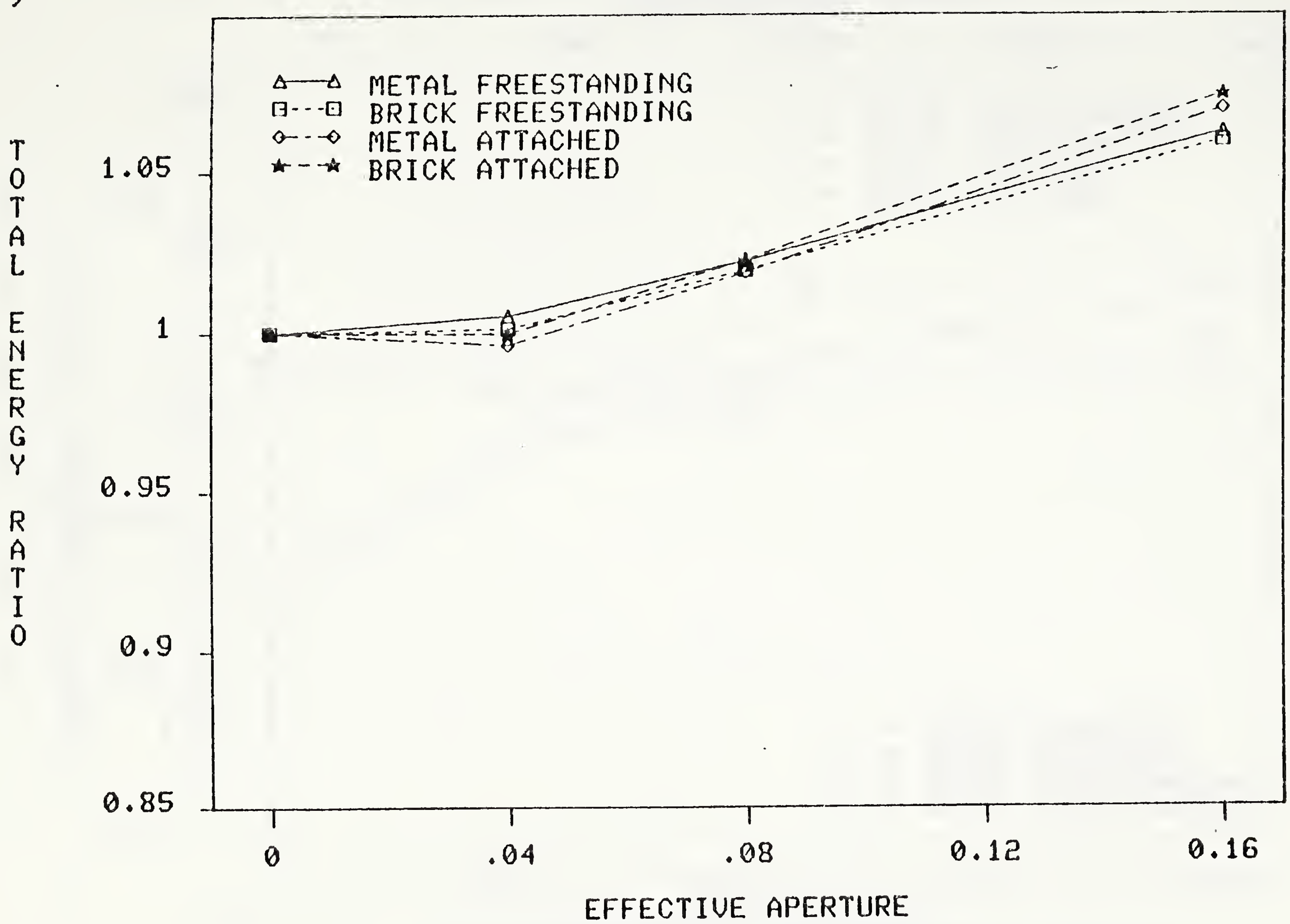


Figure 29. TOTAL ENERGY RATIO - SOUTH WINDOW (Seattle) WITH DAYLIGHT

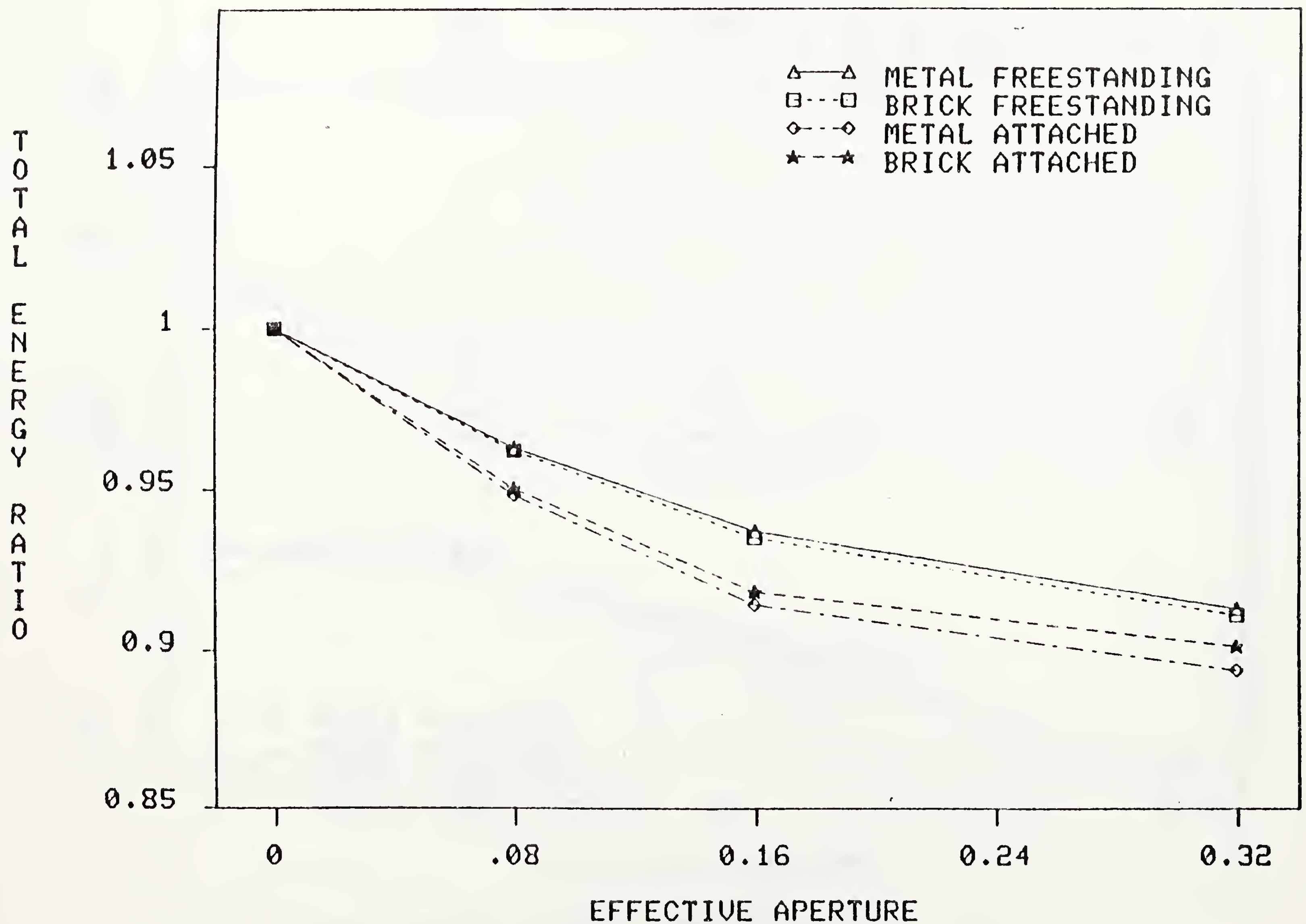


Figure 30. TOTAL ENERGY RATIO - NORTH WINDOW (Seattle) WITH DAYLIGHT

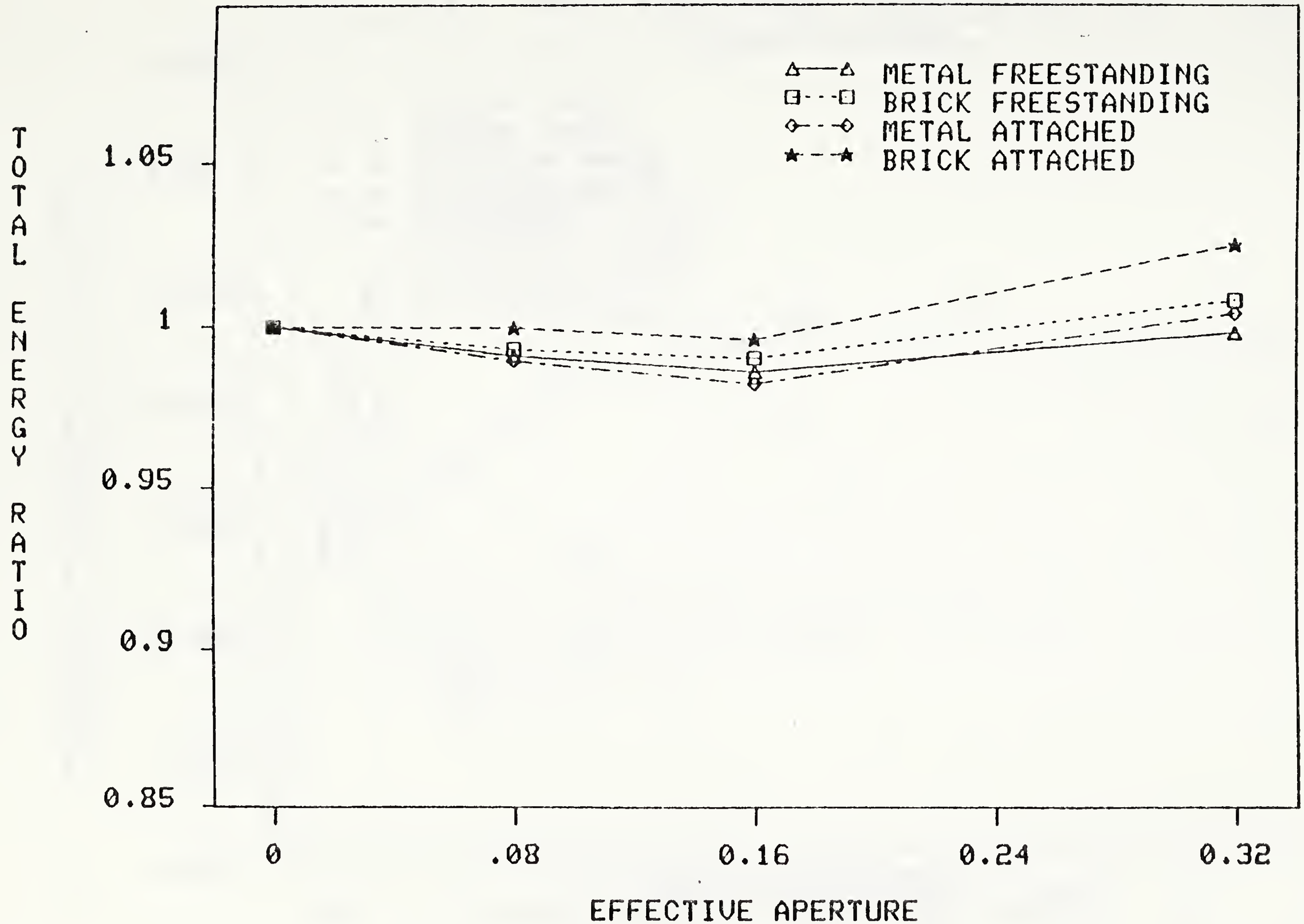


Figure 31. TOTAL ENERGY WITH DAYLIGHT (Miami)
BRICK FREESTANDING

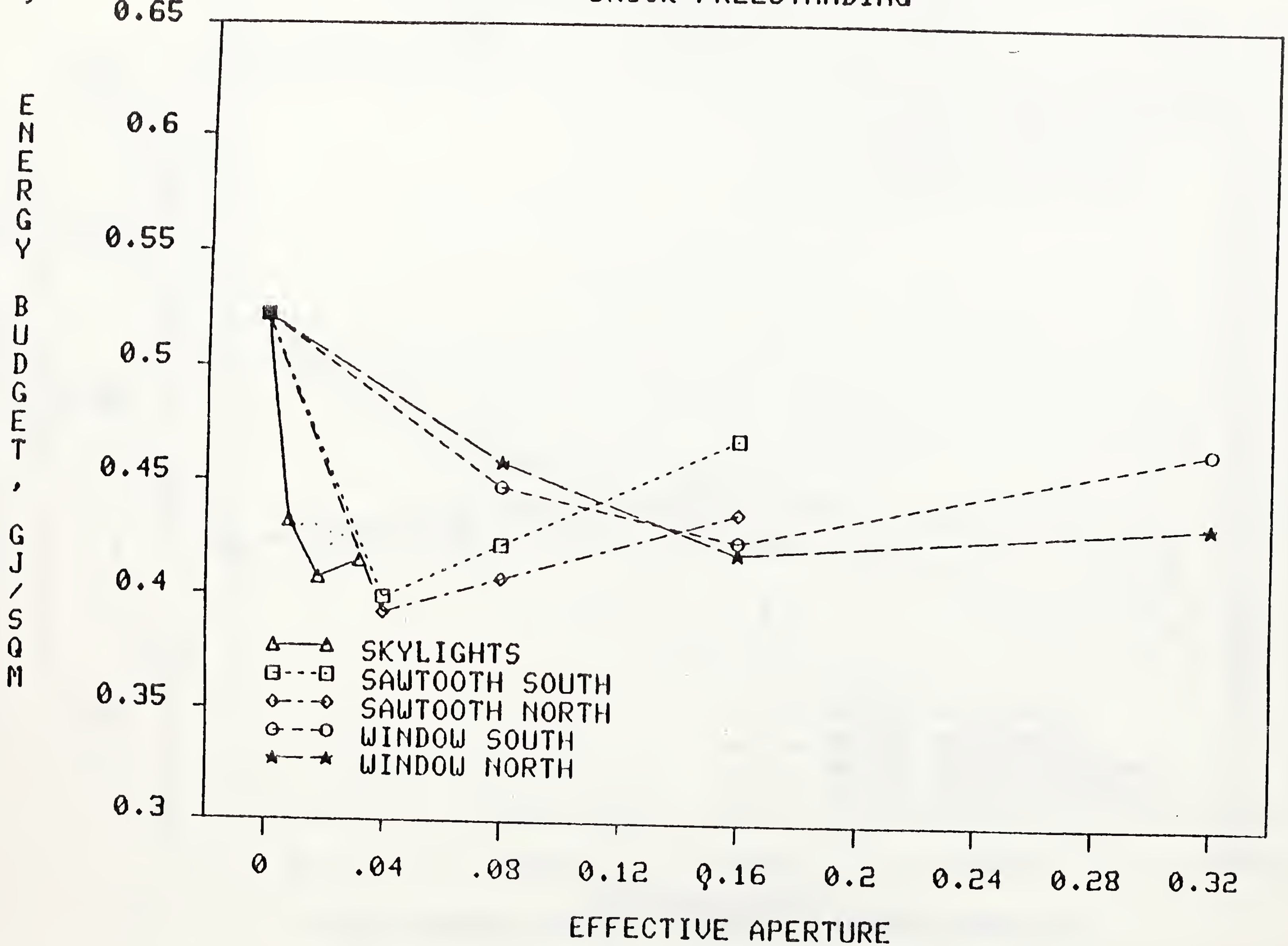


Figure 32. TOTAL ENERGY WITH DAYLIGHT (Miami)
BRICK ATTACHED

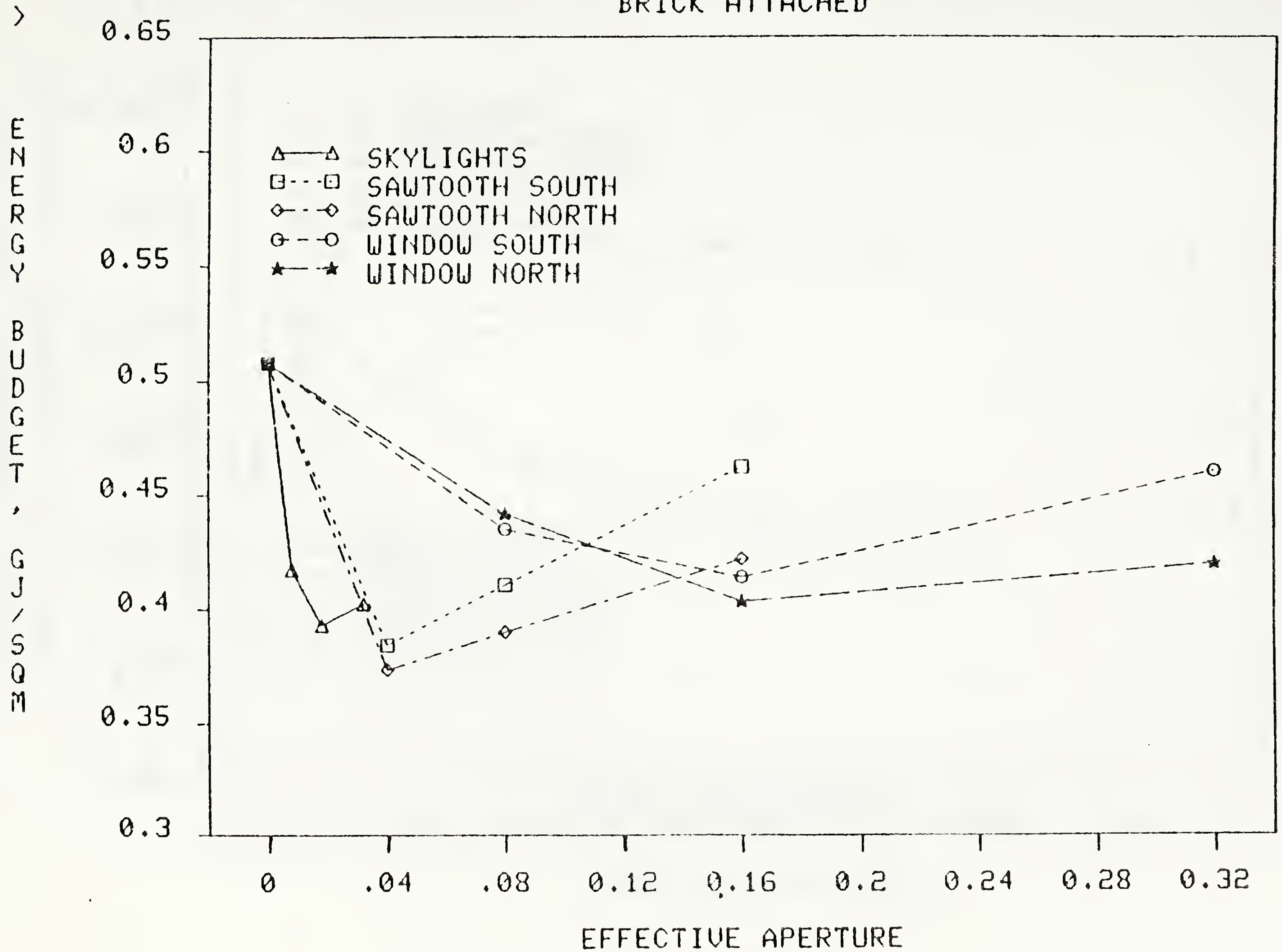


Figure 33. TOTAL ENERGY WITH DAYLIGHT (Miami)
METAL FREESTANDING

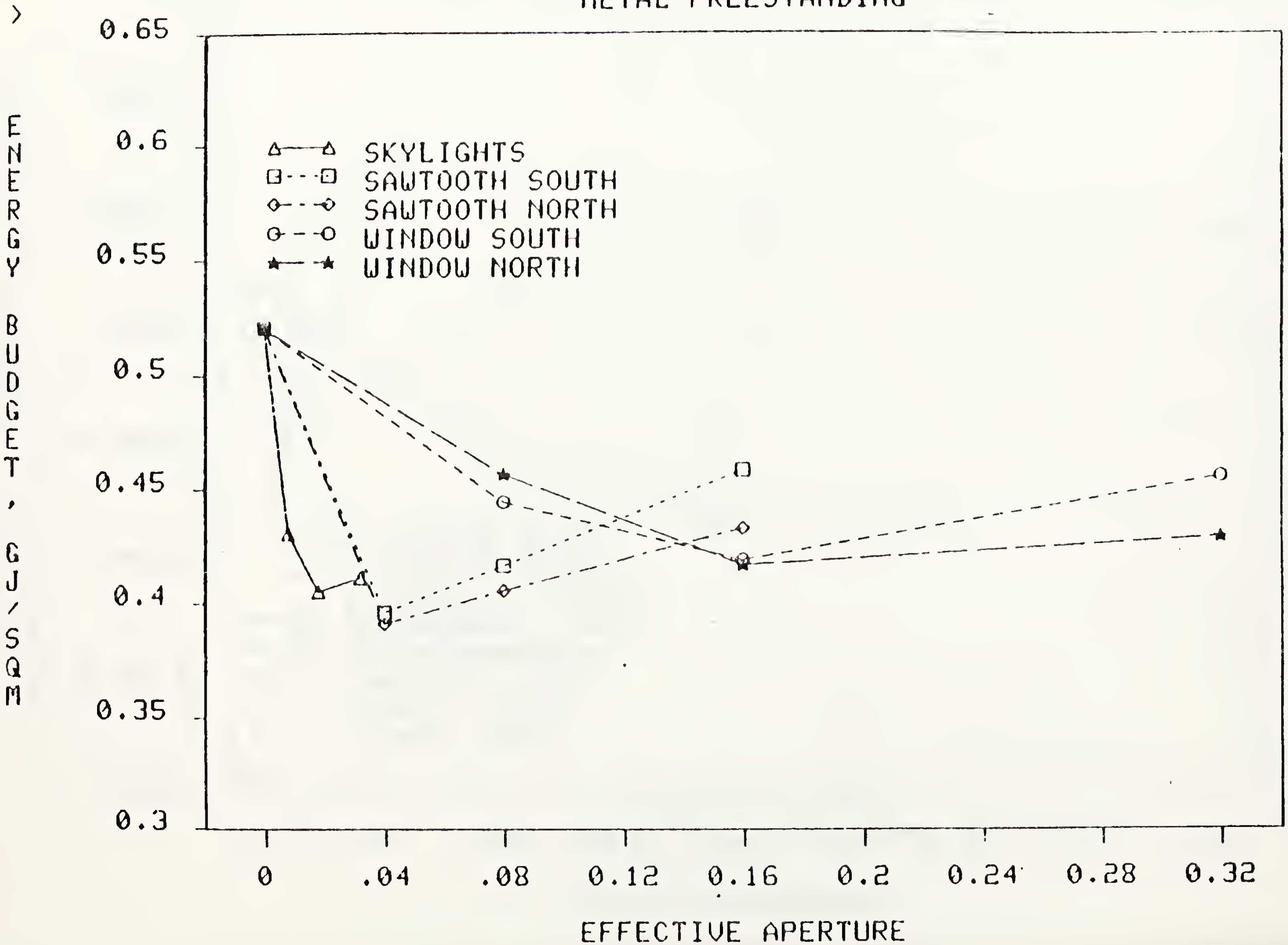


Figure 34. TOTAL ENERGY WITH DAYLIGHT (Miami)
METAL ATTACHED

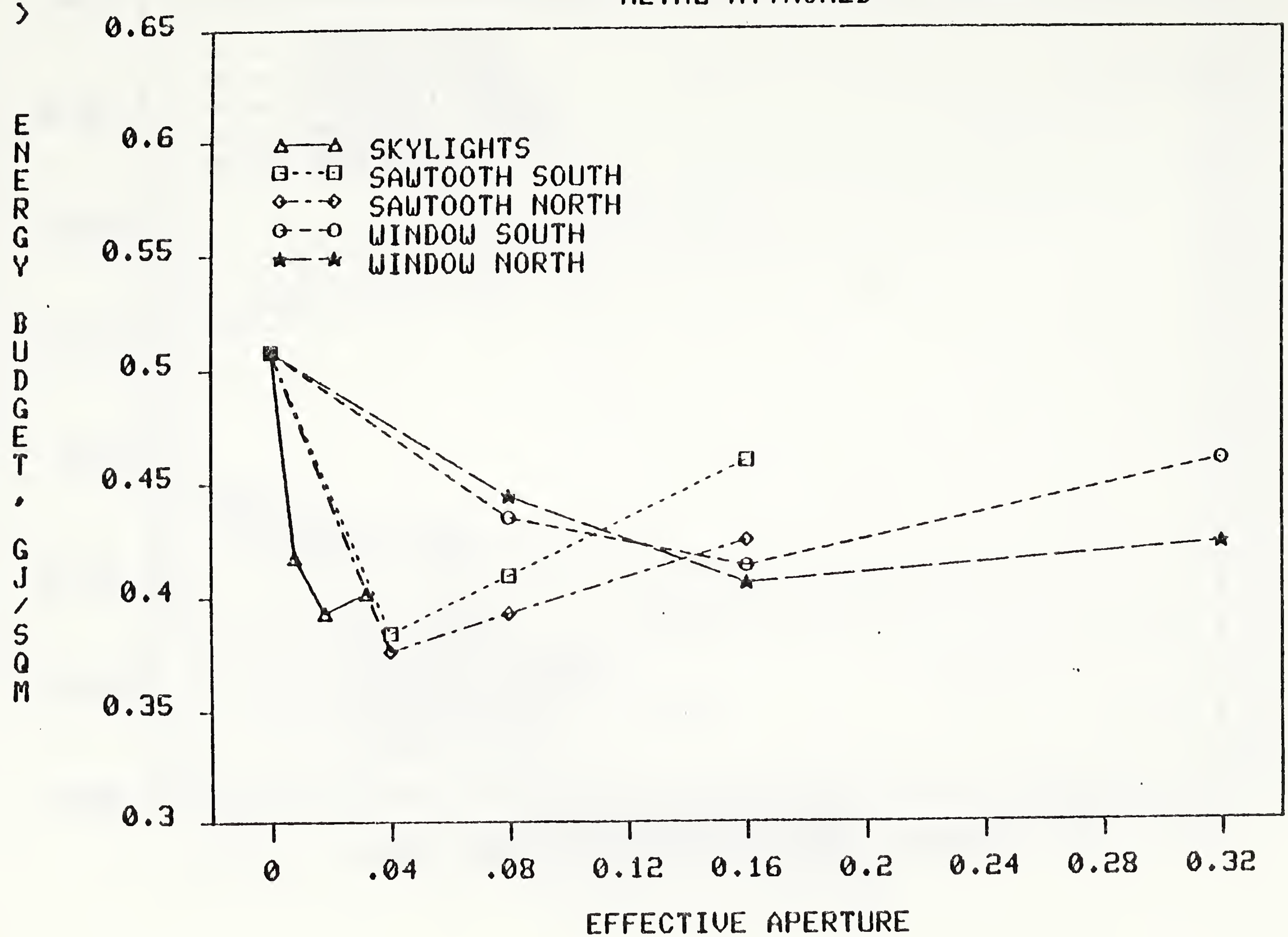


Figure 35. TOTAL ENERGY WITHOUT DAYLIGHT (Miami)
BRICK FREESTANDING

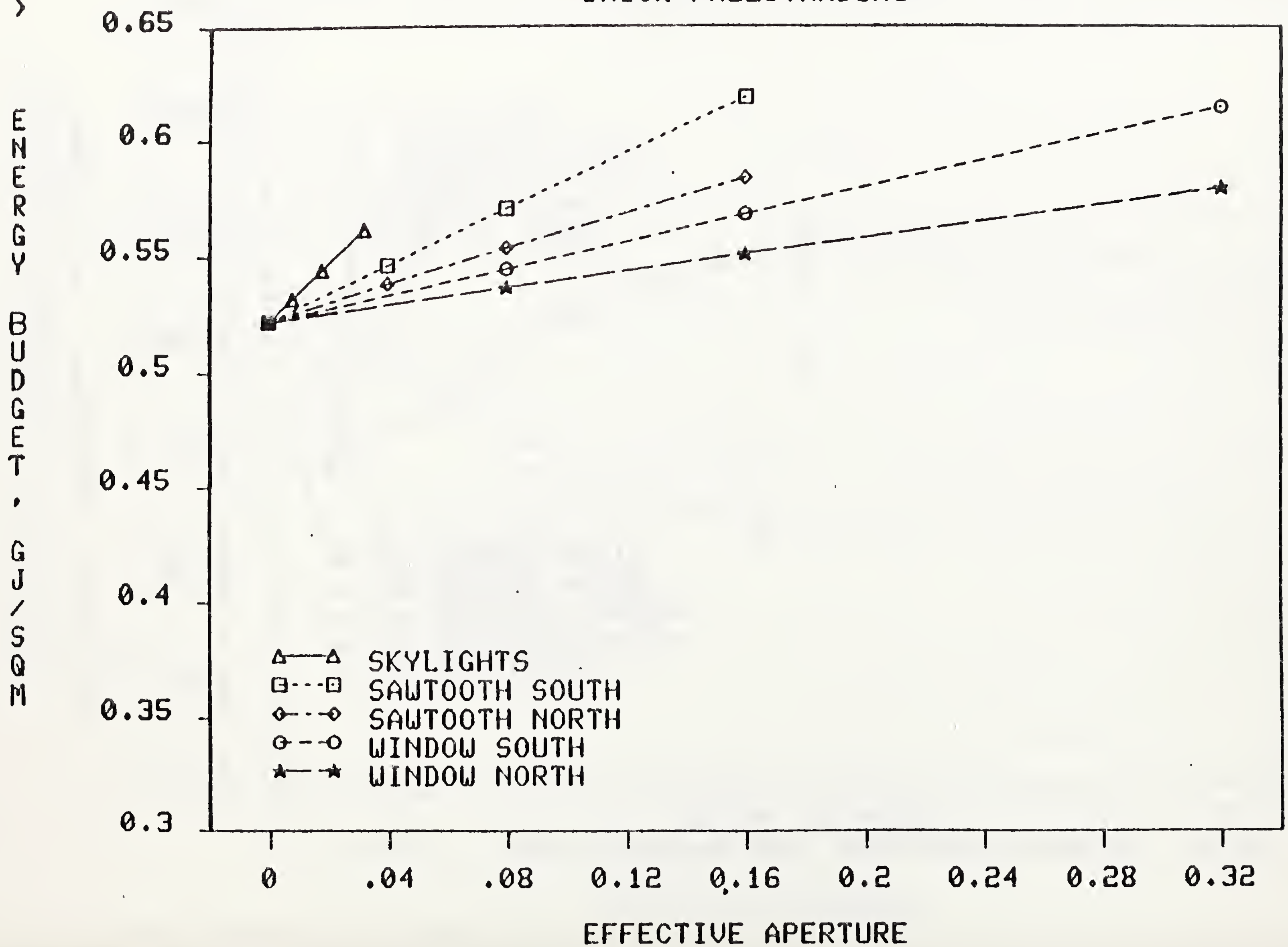


Figure 36. TOTAL ENERGY WITHOUT DAYLIGHT (Miami).
BRICK ATTACHED

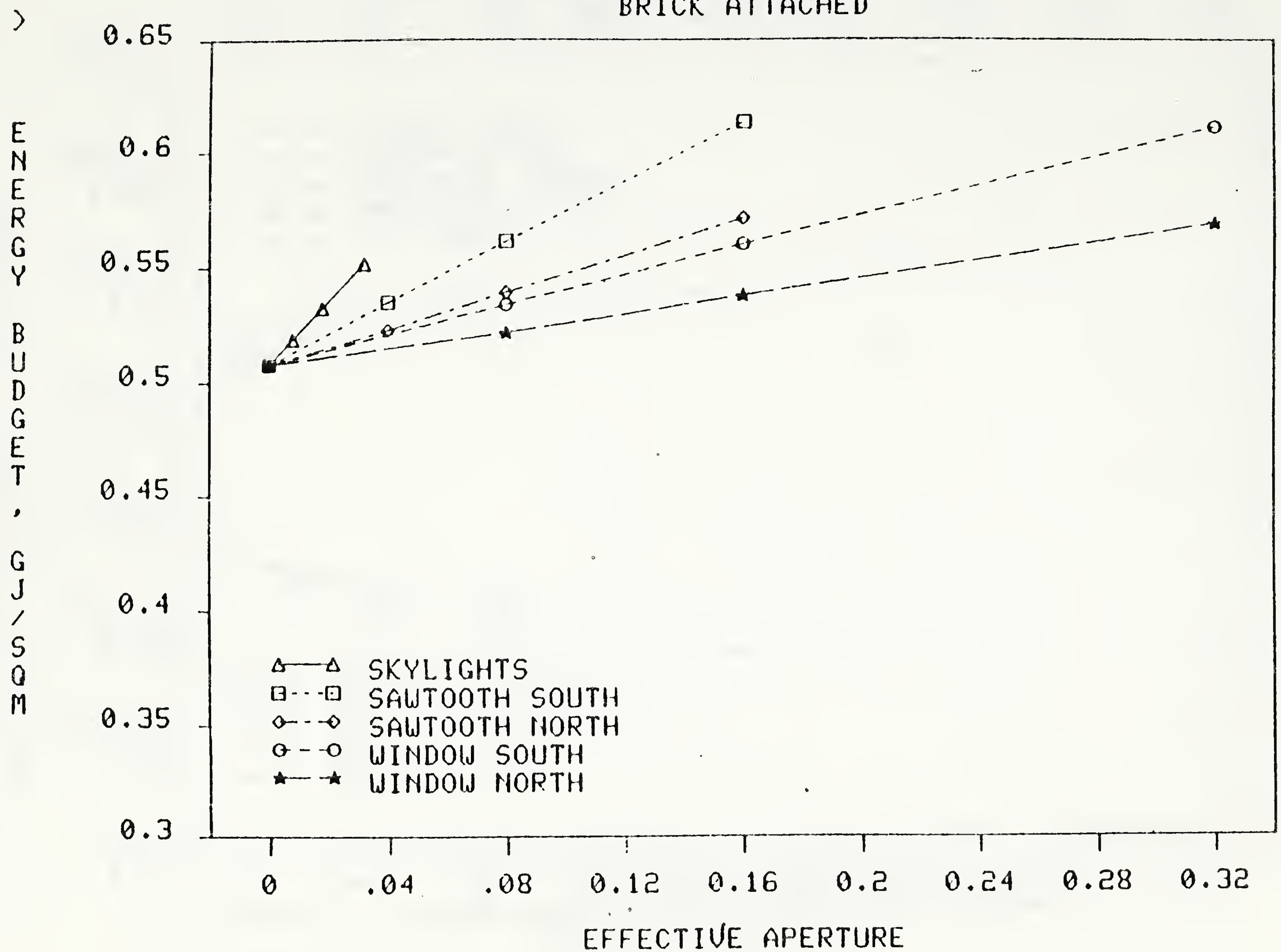


Figure 37. TOTAL ENERGY WITHOUT DAYLIGHT (Miami)
METAL FREESTANDING

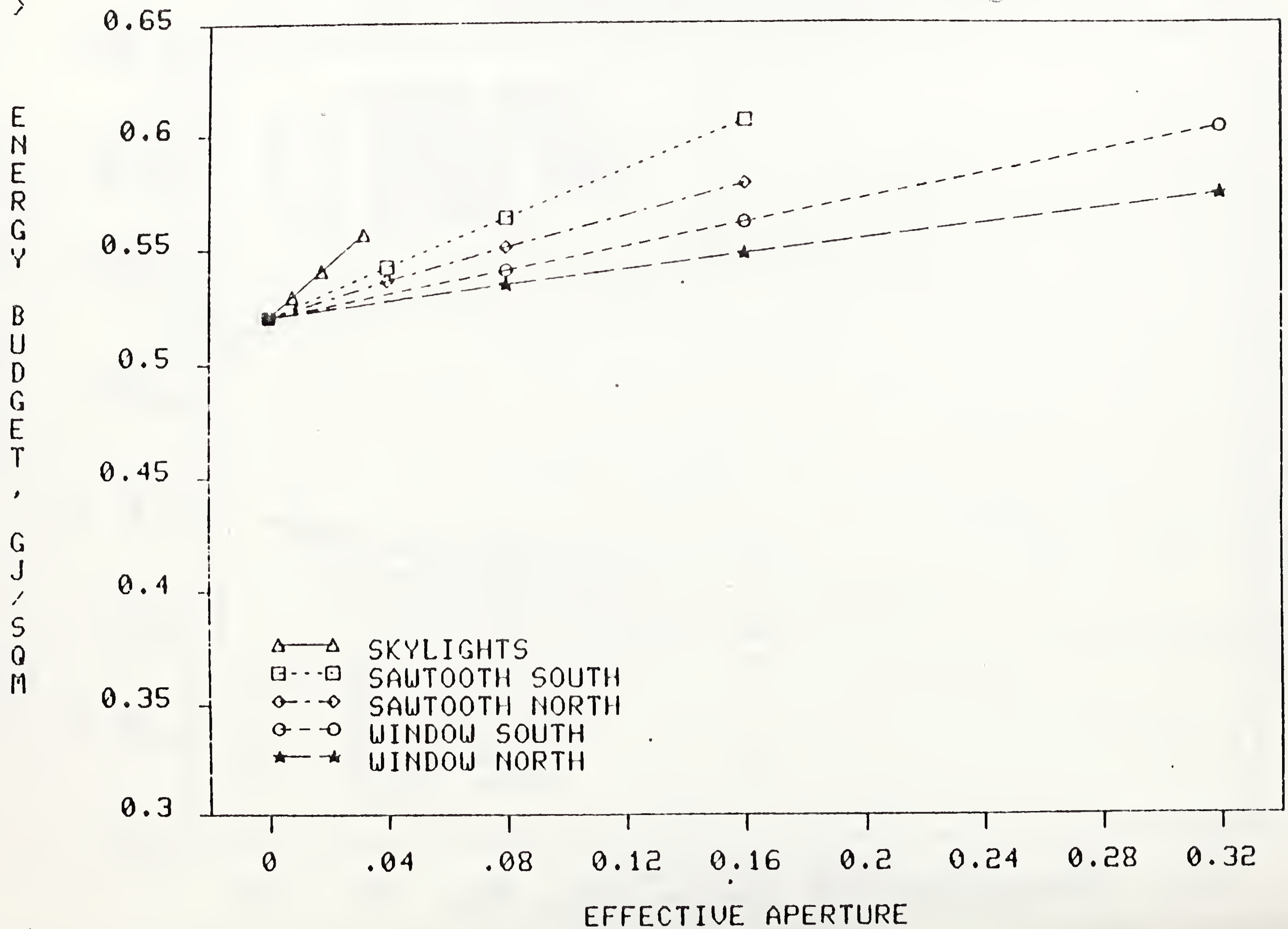


Figure 38. TOTAL ENERGY WITHOUT DAYLIGHT (Miami)
METAL ATTACHED

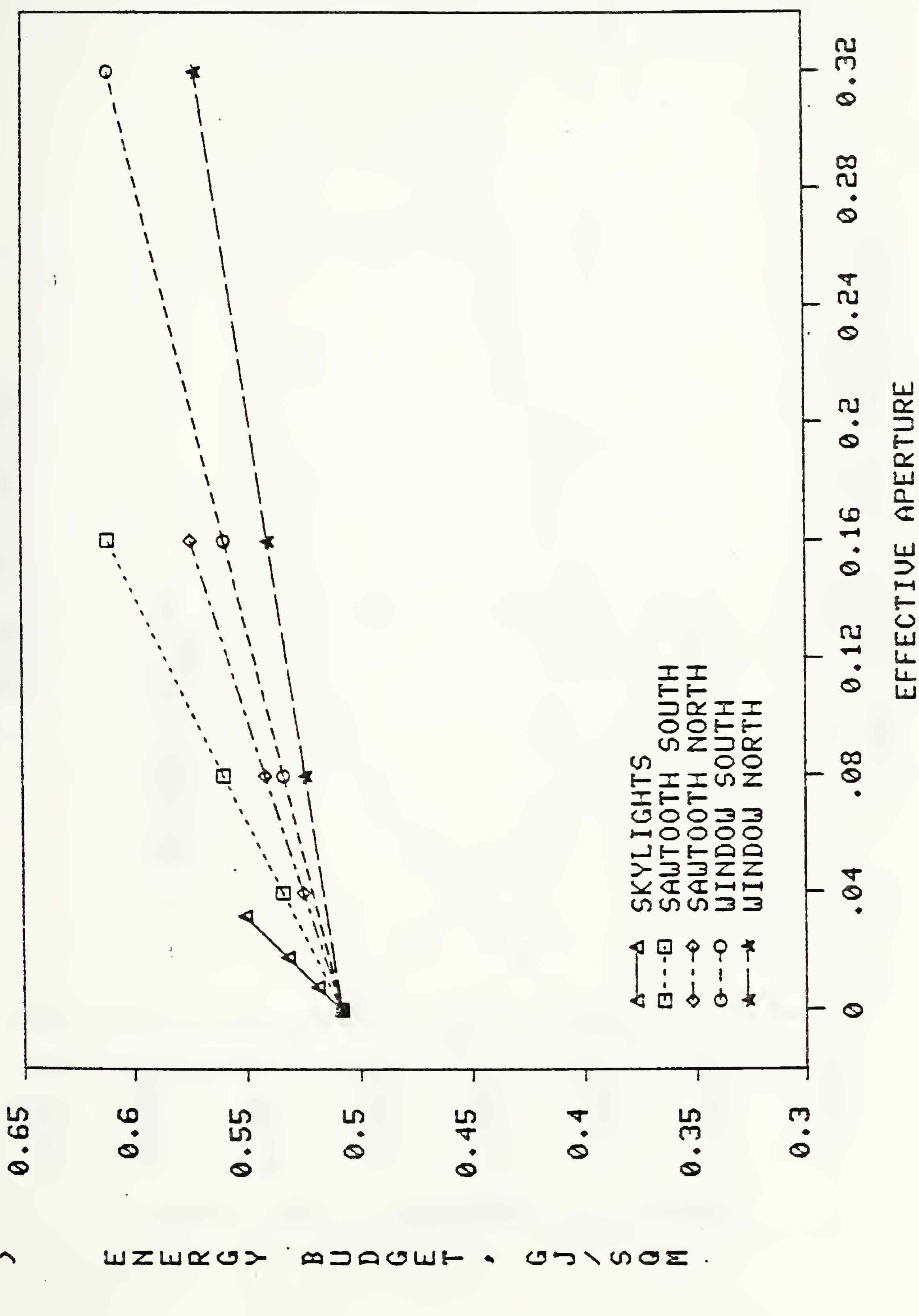


Figure 39. TOTAL ENERGY - SKYLIGHTS (Miami)
BRICK FREESTANDING

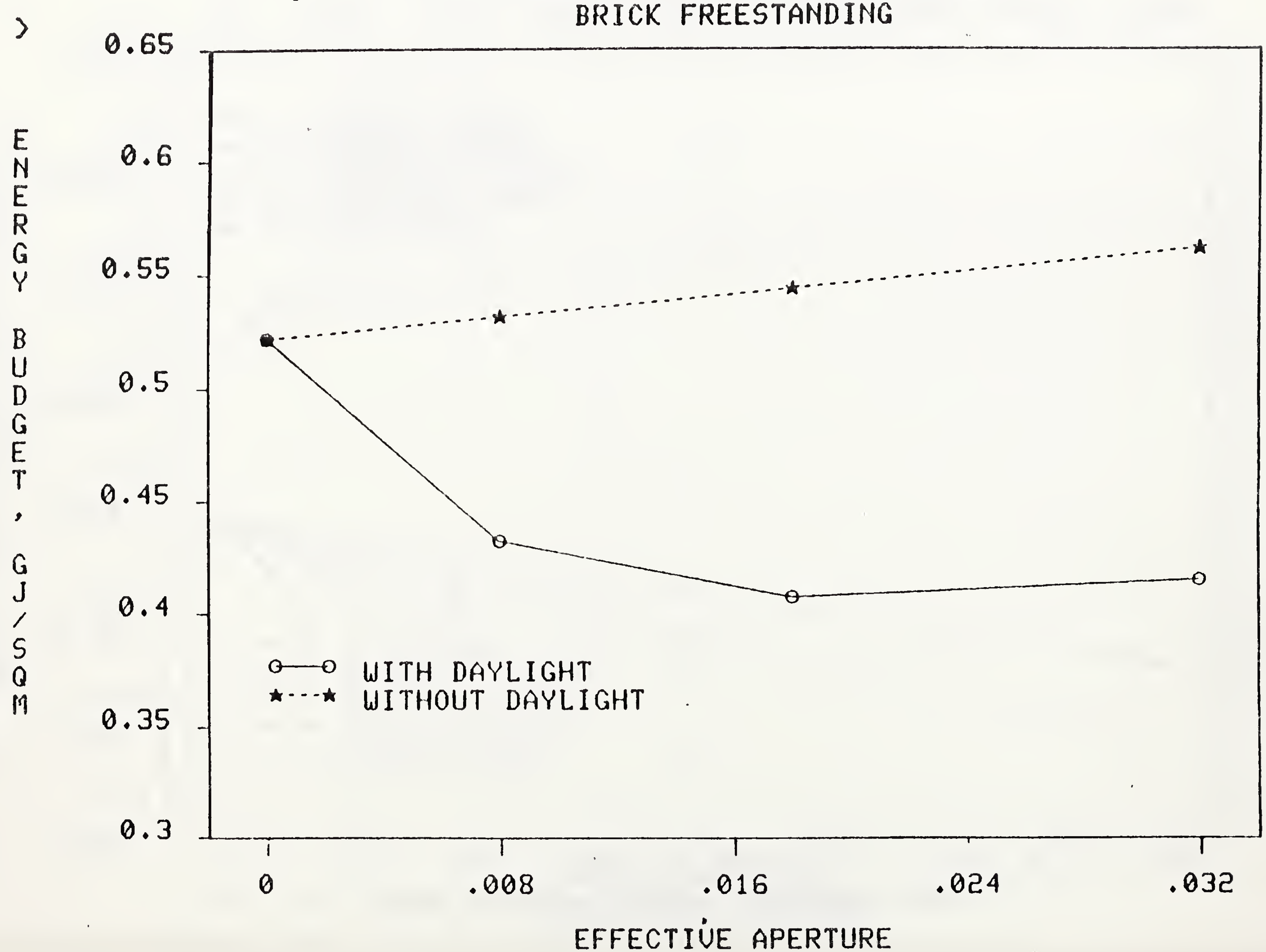
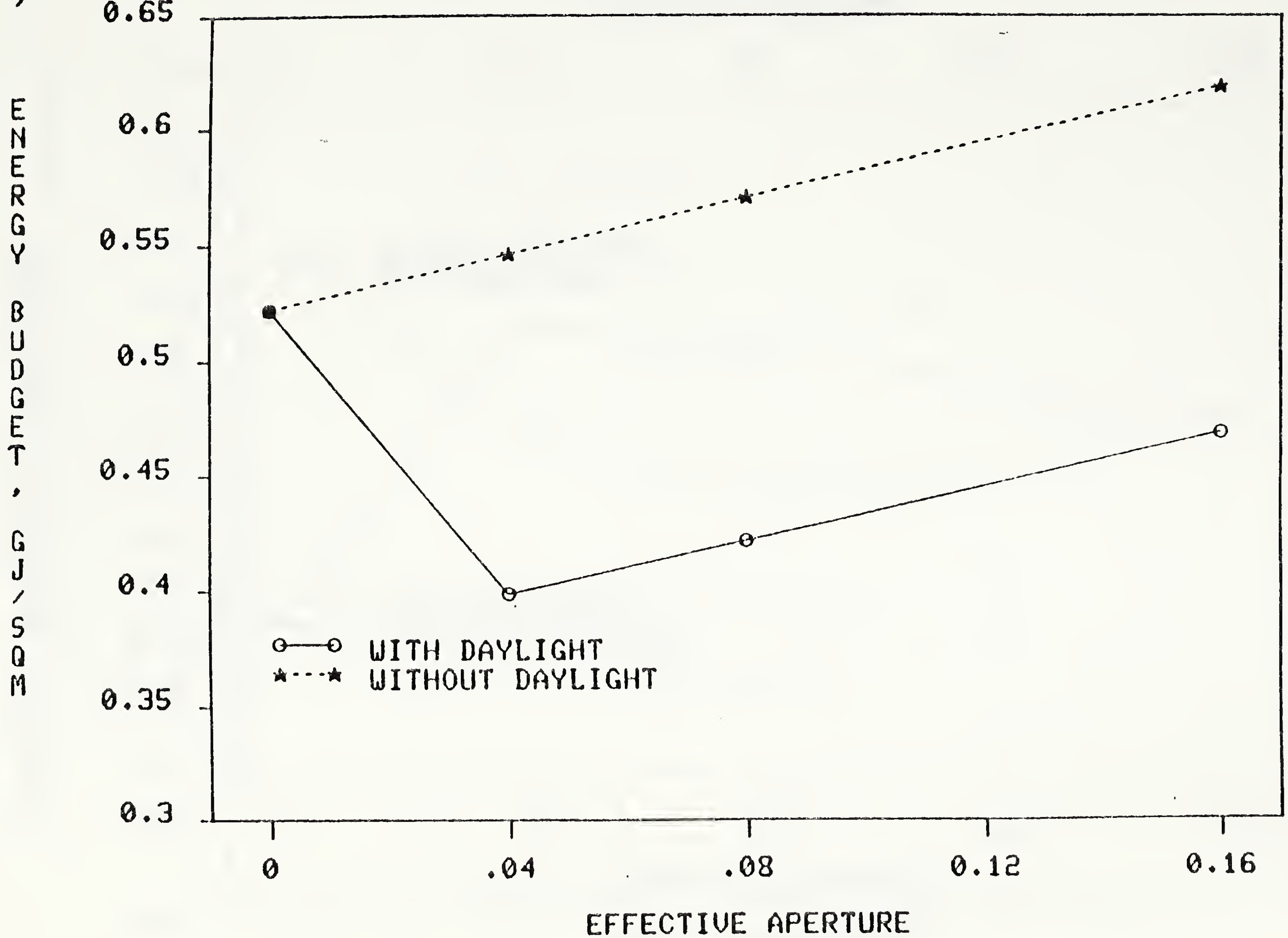


Figure 40. TOTAL ENERGY - SOUTH SAWTOOTH (Miami)
BRICK FREESTANDING



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BRICK FREESTANDING

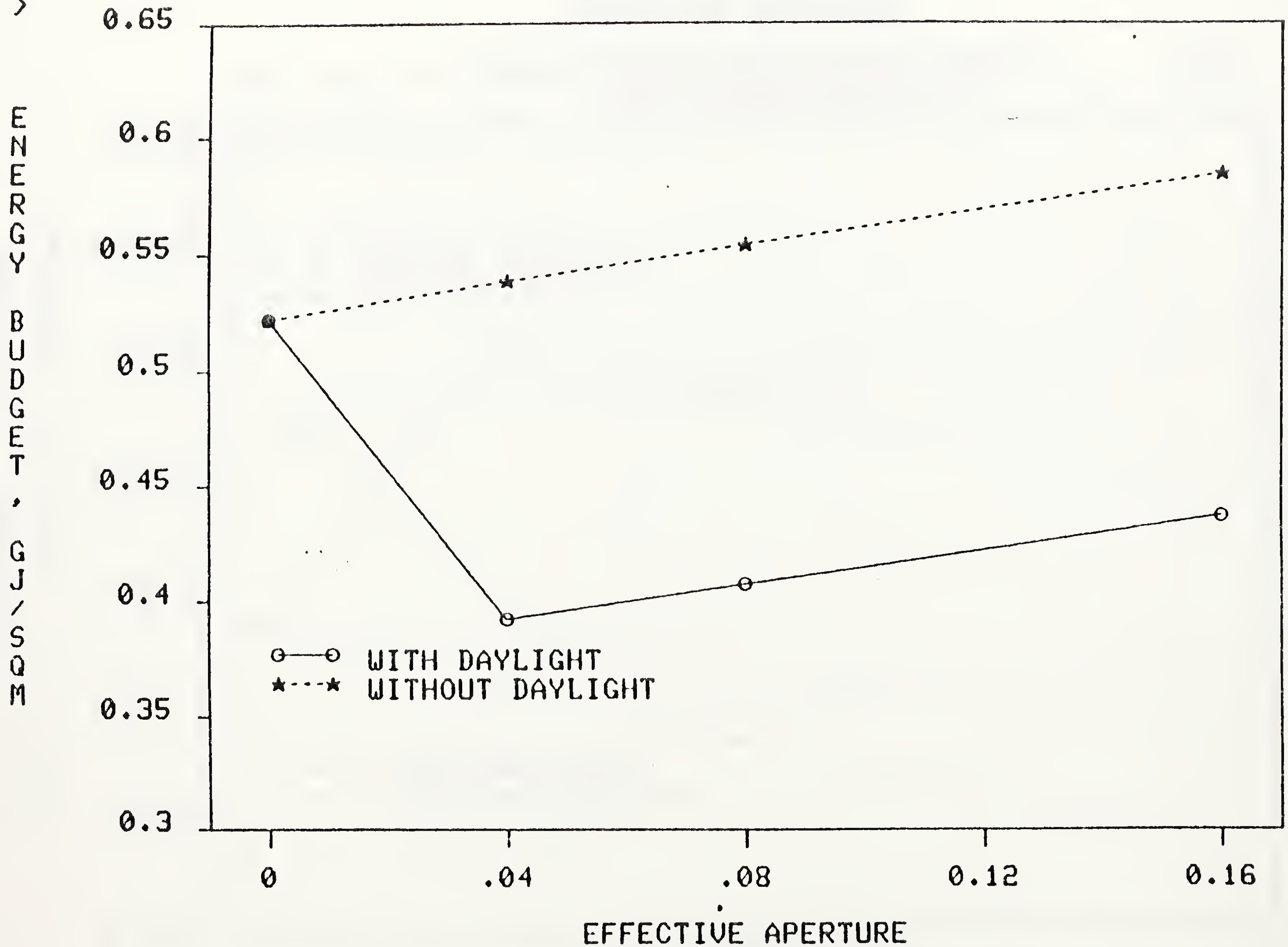


Figure 42. TOTAL ENERGY - SOUTH WINDOW (Miami)
BRICK FREESTANDING

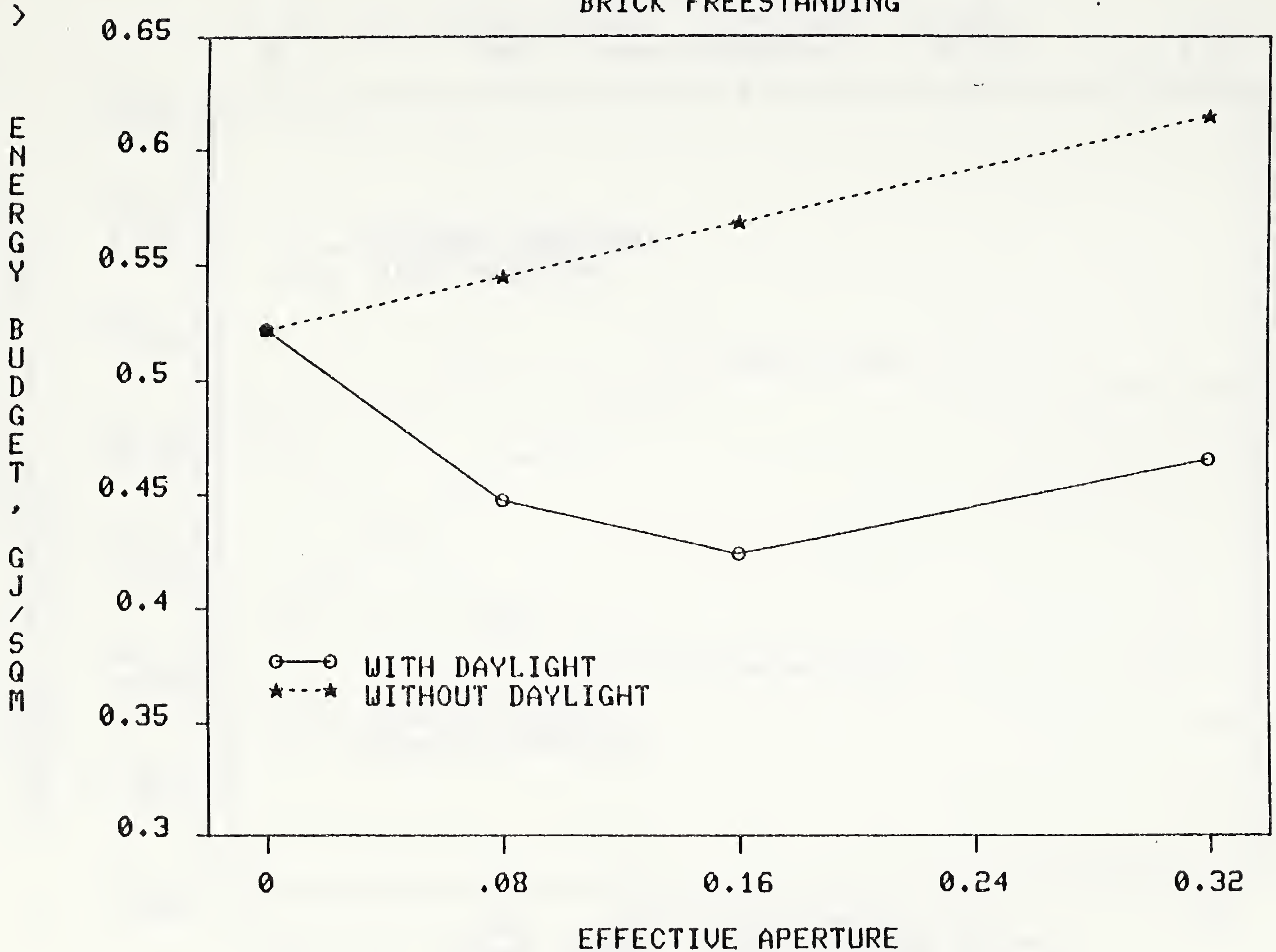


Figure 43. TOTAL ENERGY - NORTH WINDOW (Miami)
BRICK FREESTANDING

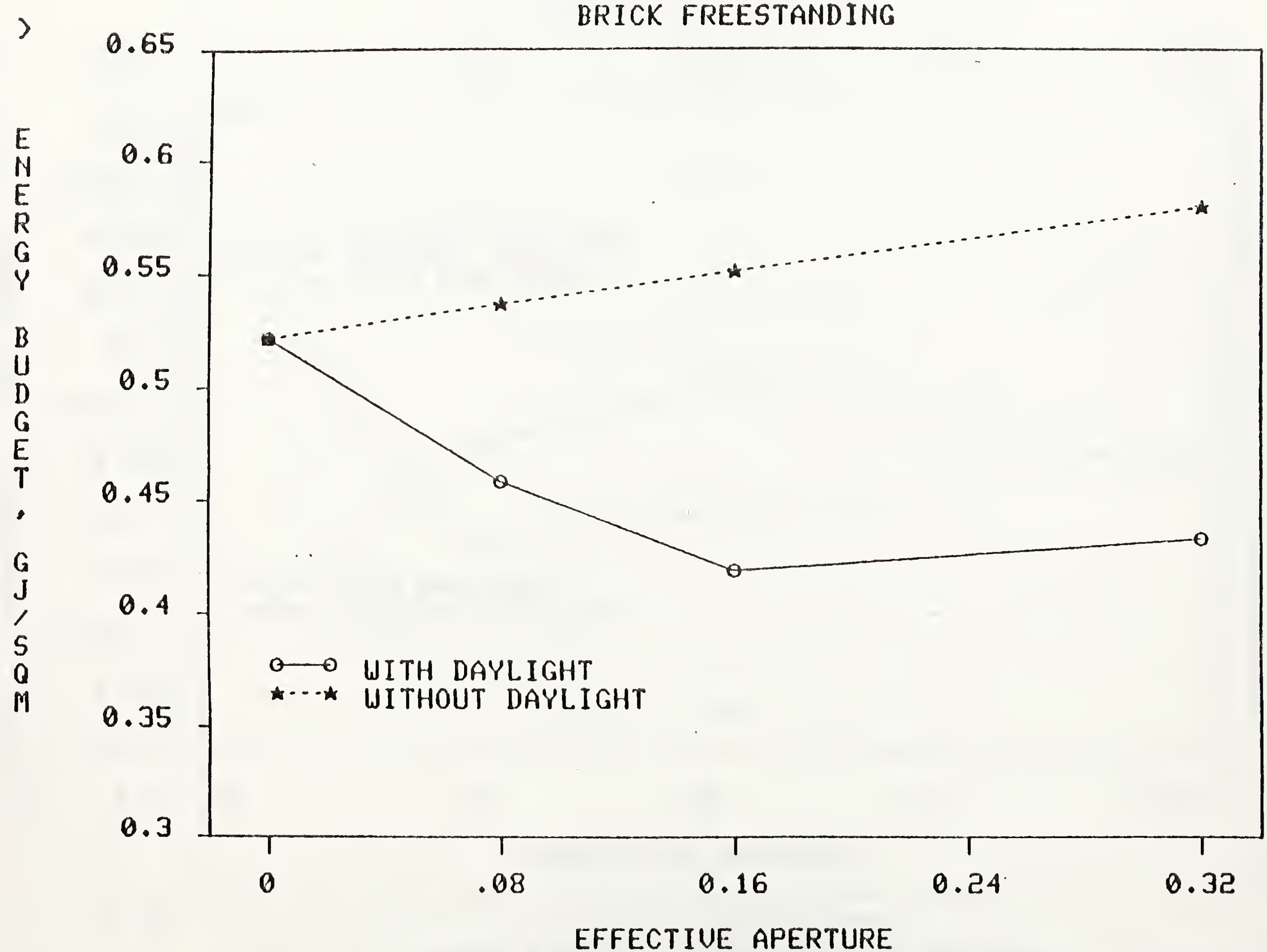
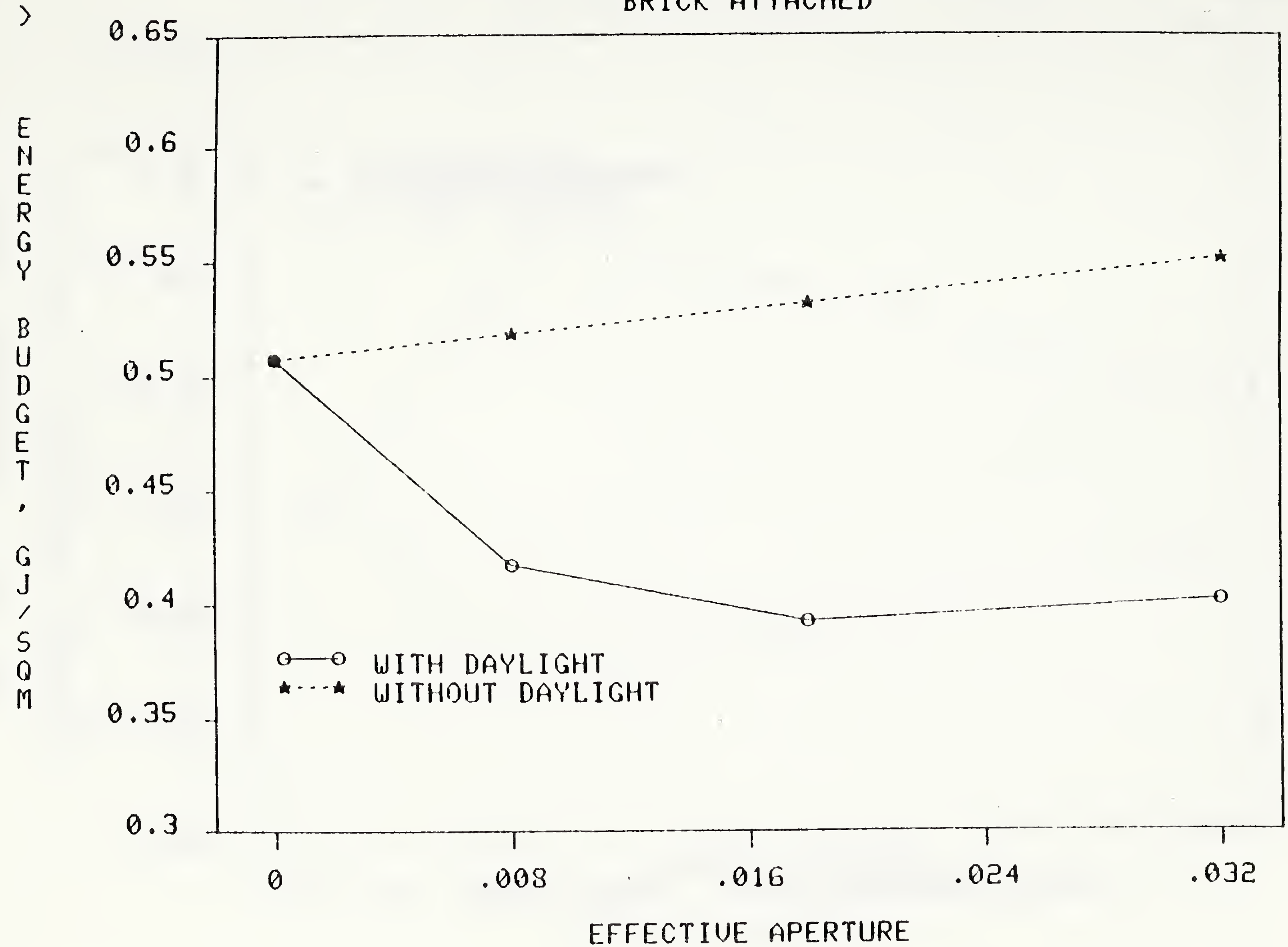


Figure 44. TOTAL ENERGY - SKYLIGHTS (Miami)
BRICK ATTACHED



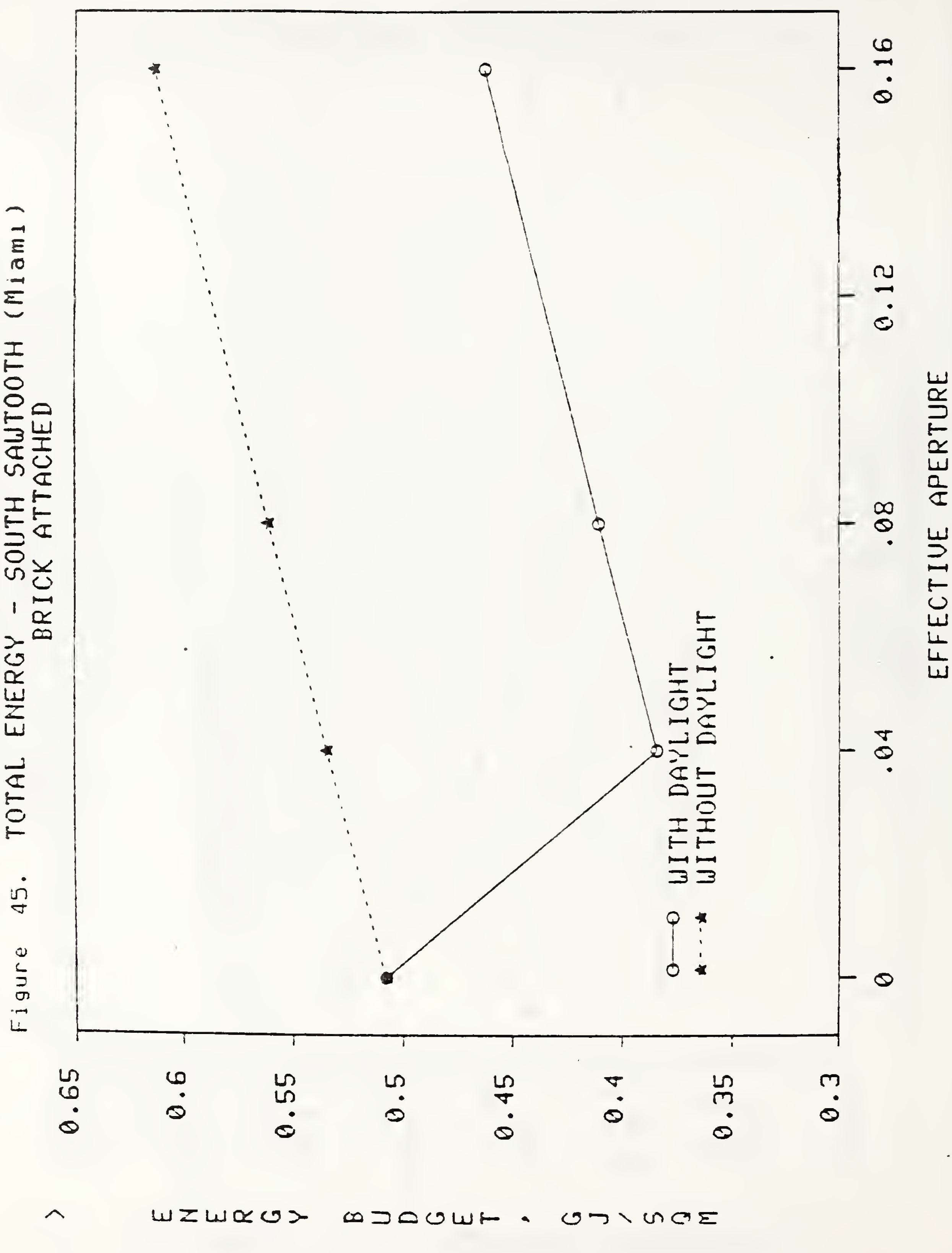
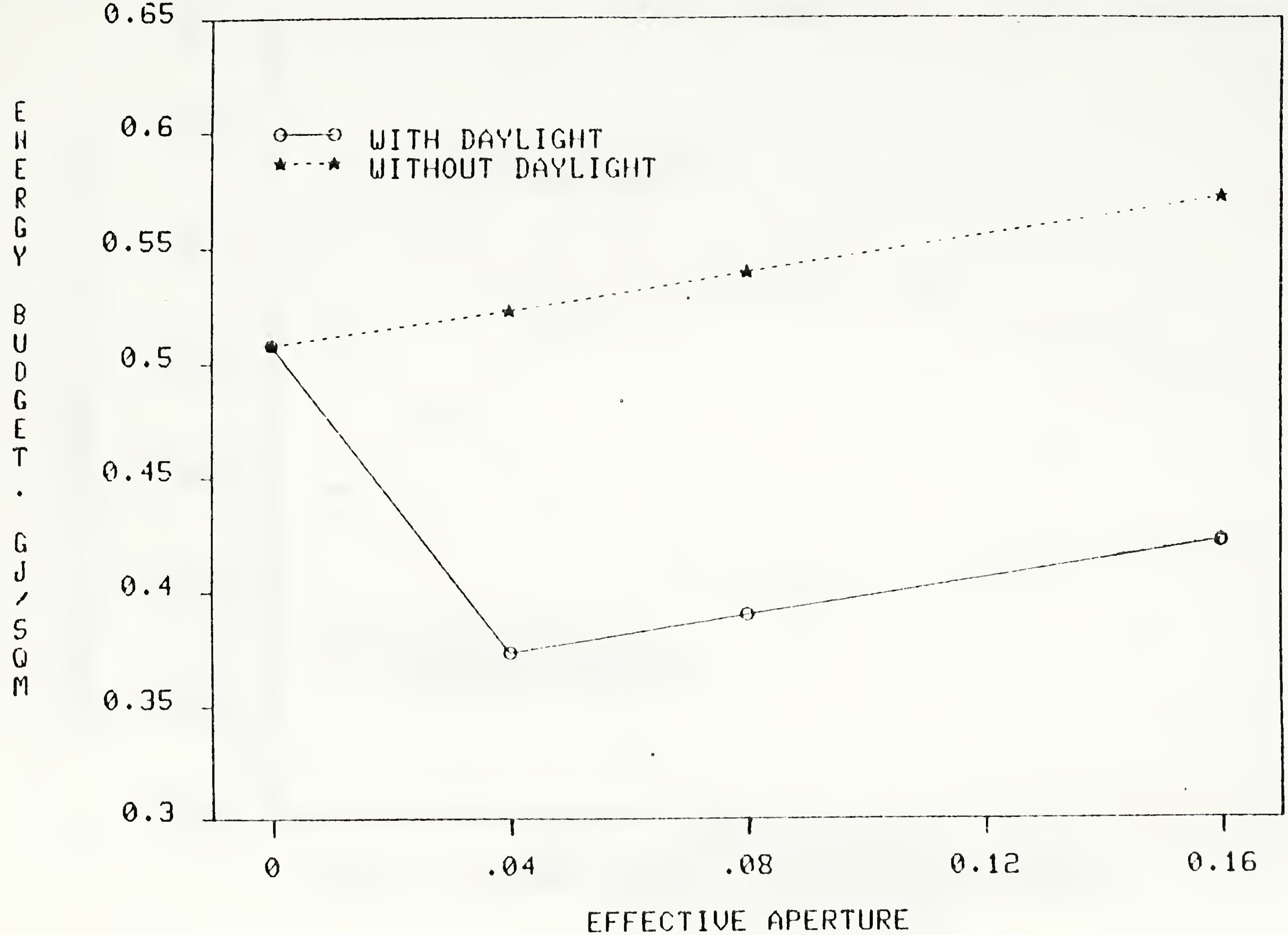



Figure 45. TOTAL ENERGY - SOUTH SAWTOOTH (Miami)
BRICK ATTACHED

Figure 46. TOTAL ENERGY - NORTH SAWTOOTH (Miami)
BRICK ATTACHED



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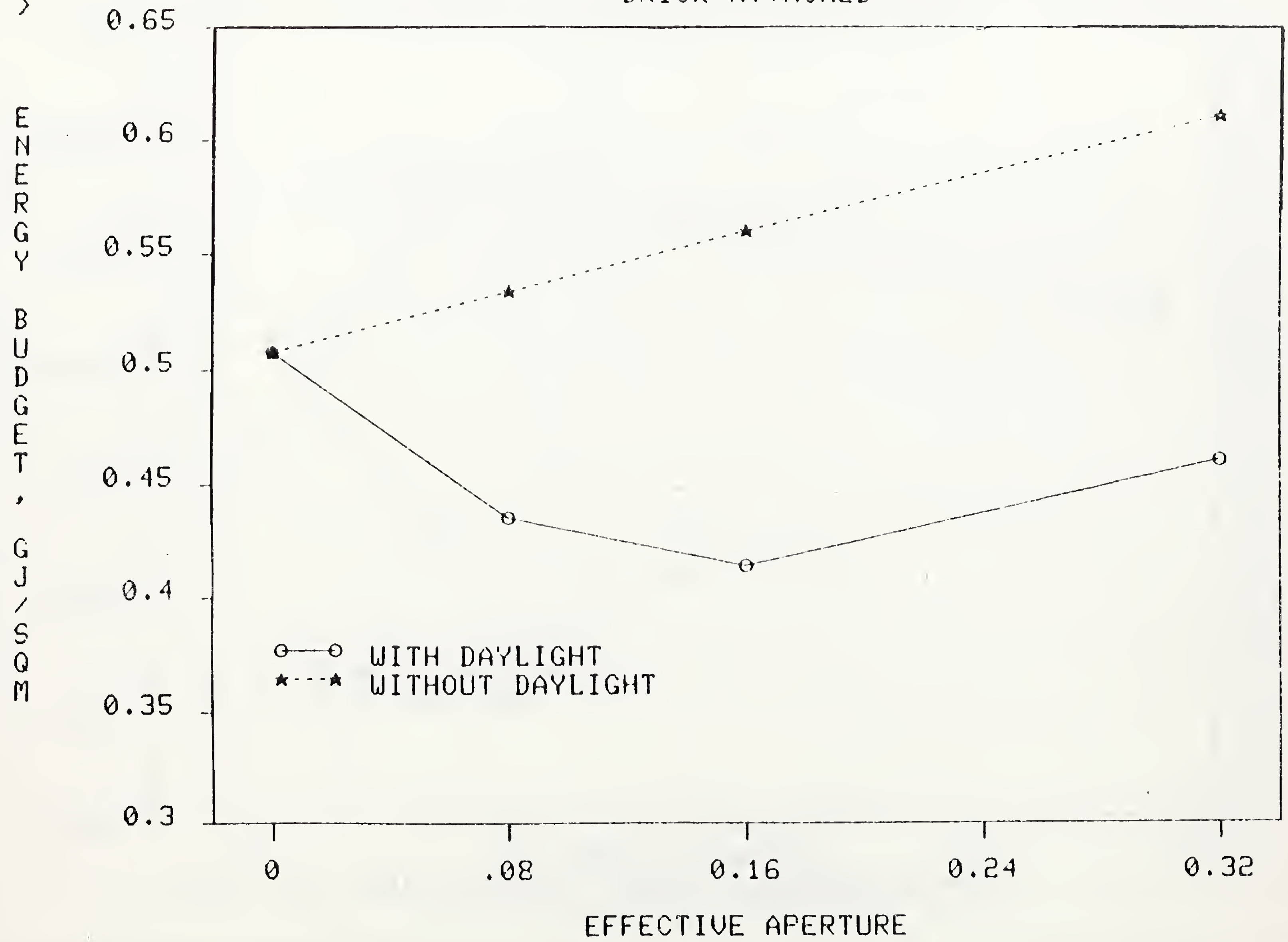


Figure 48. TOTAL ENERGY - NORTH WINDOW (Miami)
BRICK ATTACHED

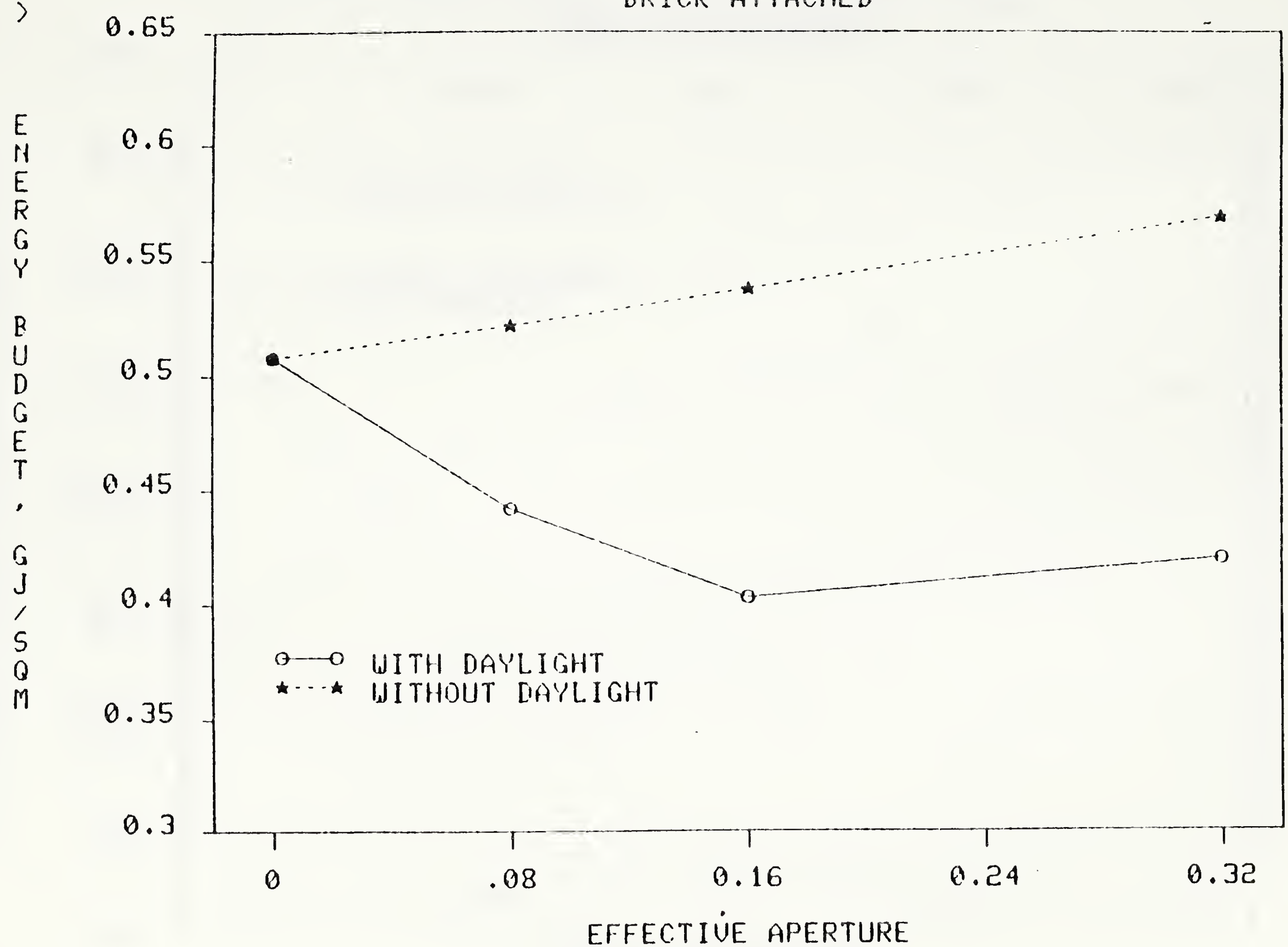


Figure 49. TOTAL ENERGY - SKYLIGHTS (Miami)
METAL FREESTANDING

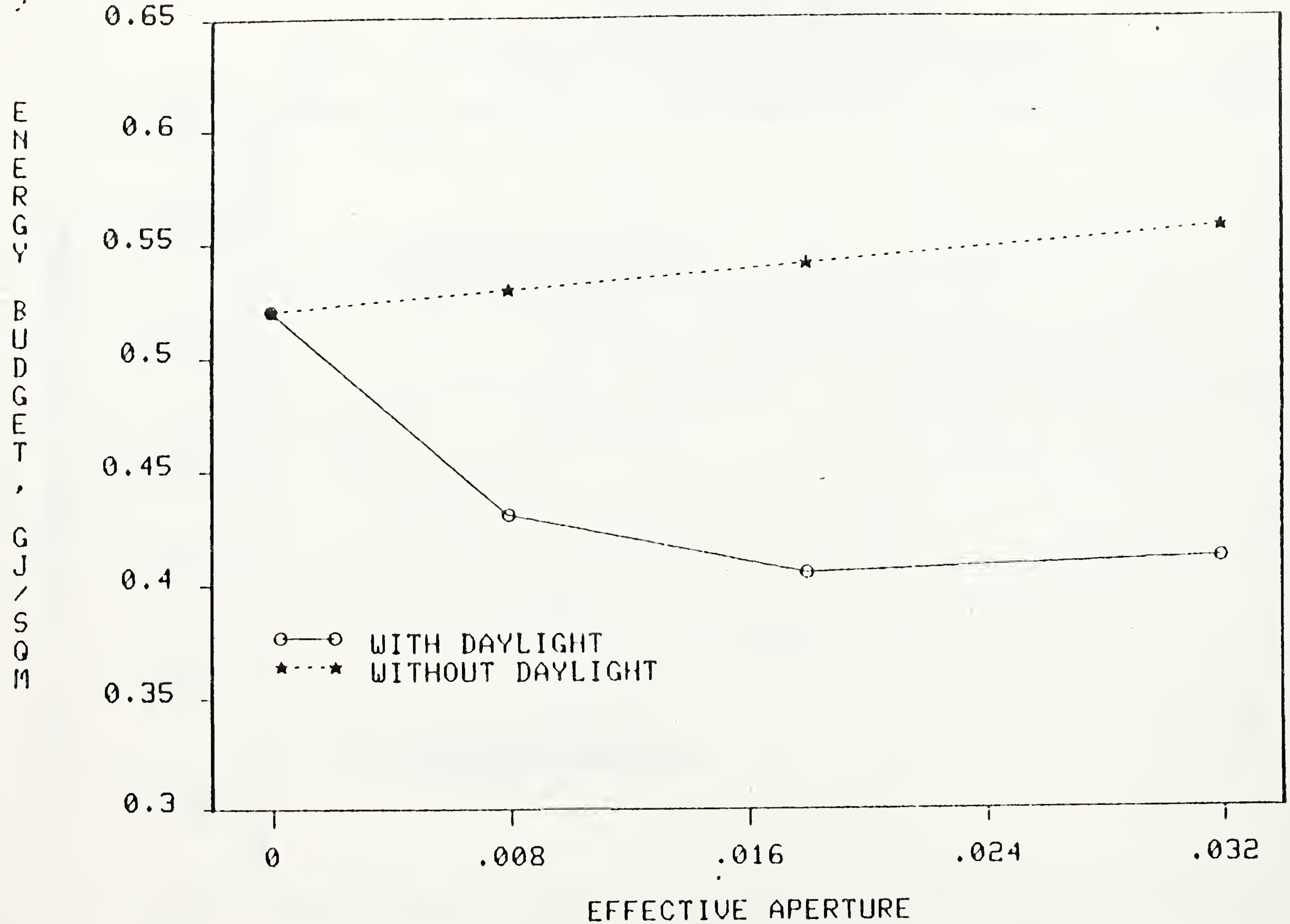


Figure 50. TOTAL ENERGY - SOUTH SAWTOOTH (Miami)
METAL FREESTANDING

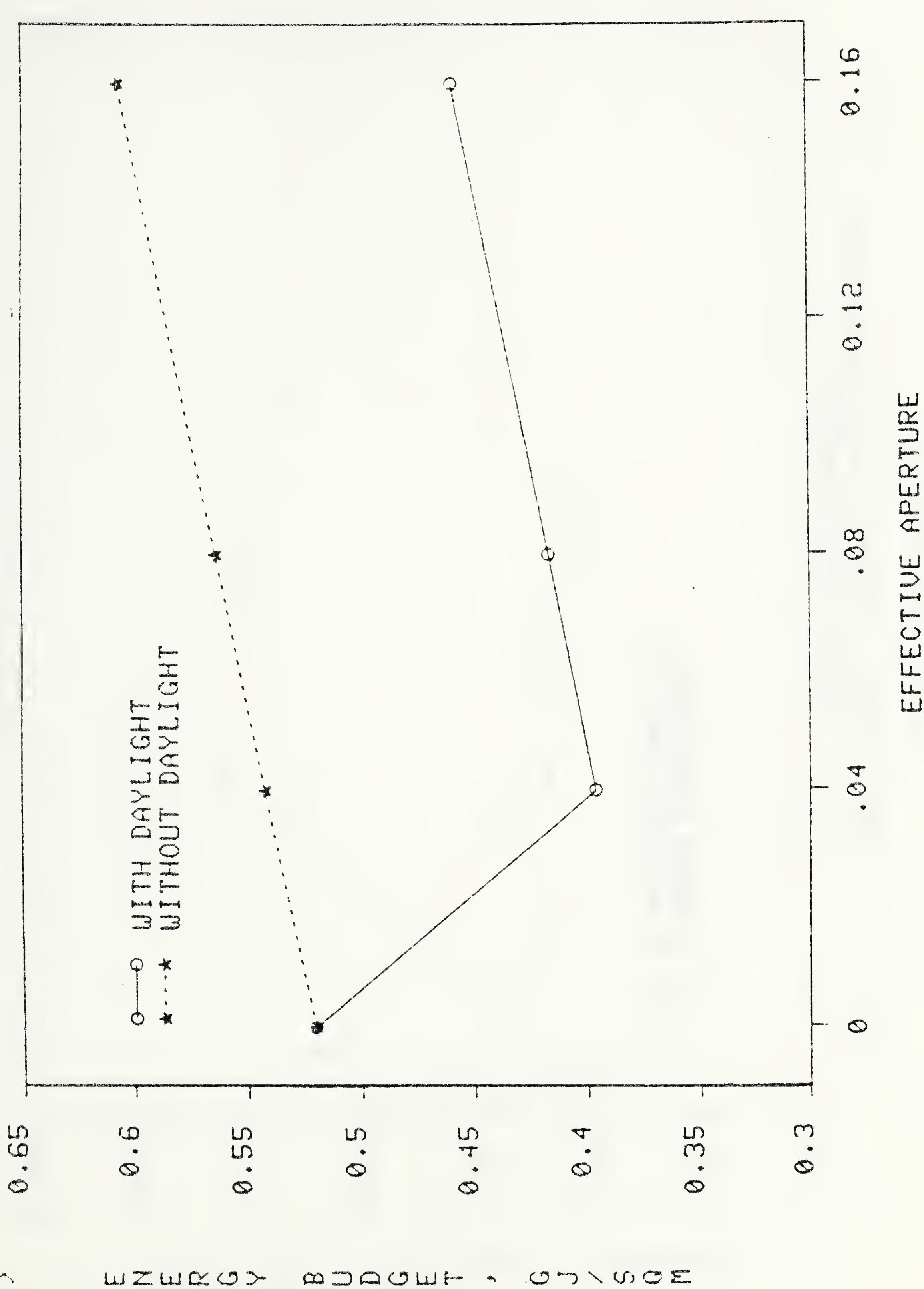


Figure 51. TOTAL ENERGY - NORTH SAWTOOTH (Miami)
METAL FREESTANDING

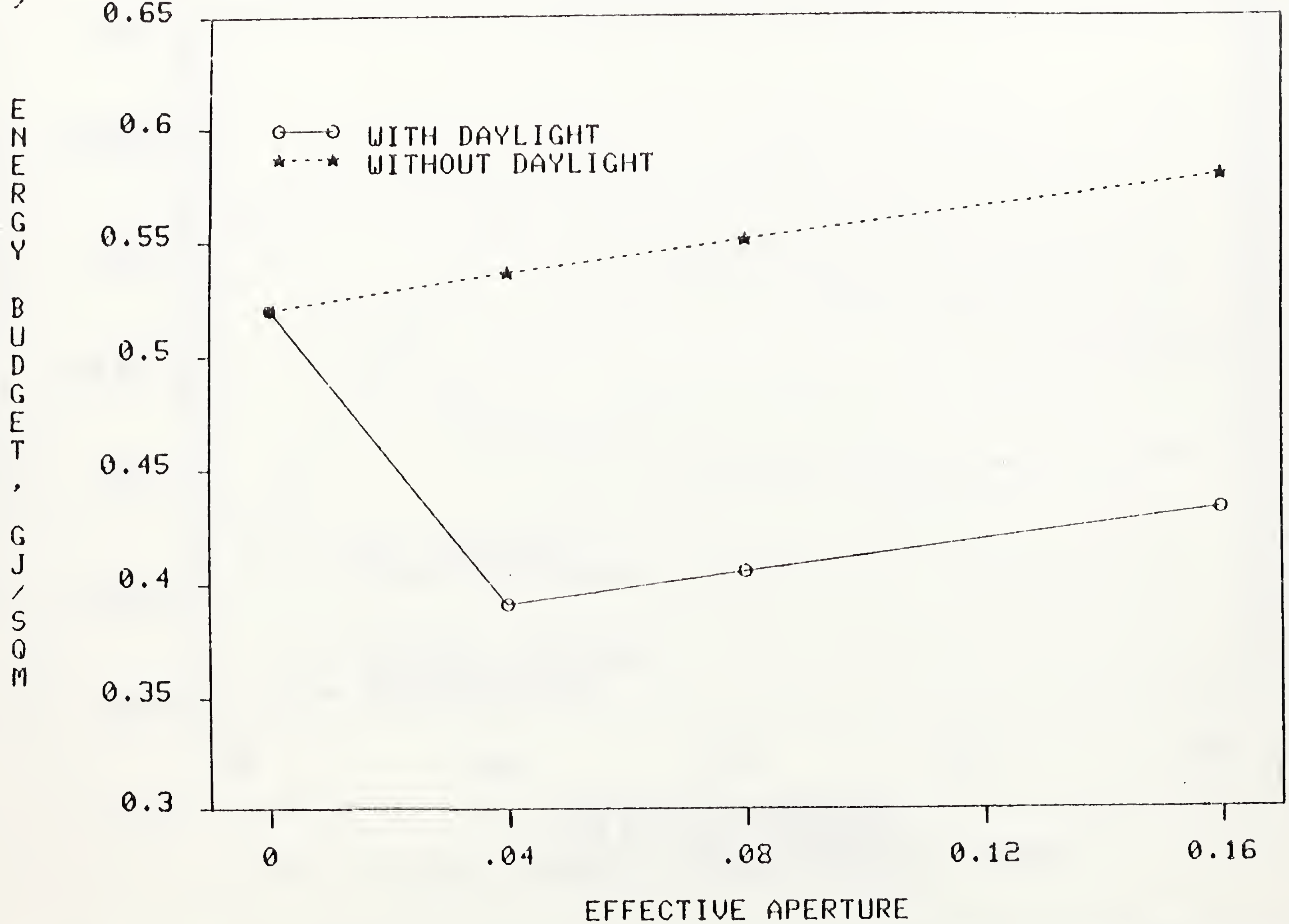


Figure 52. TOTAL ENERGY - SOUTH WINDOW (Miami)
METAL FREESTANDING

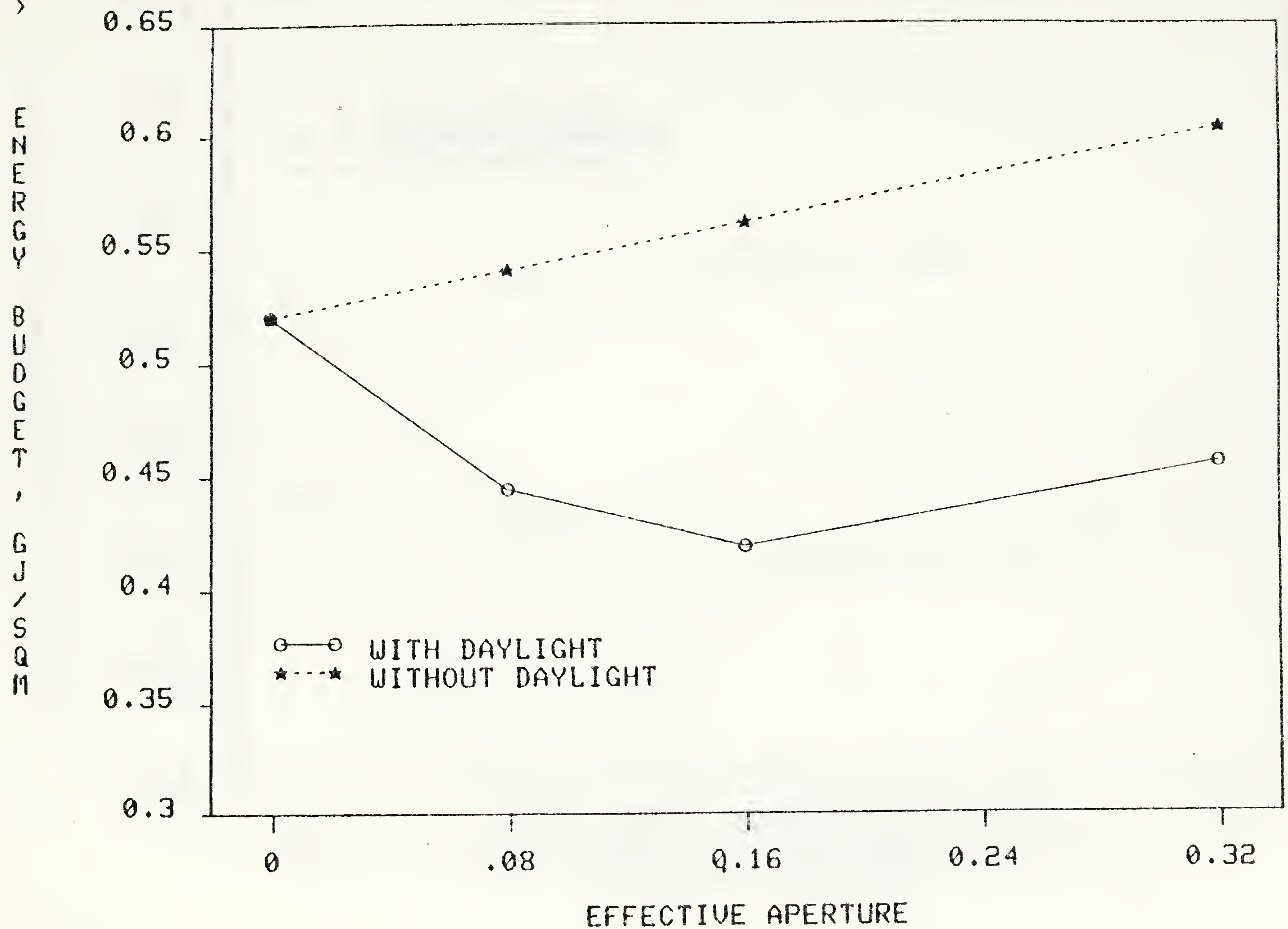


Figure 53. TOTAL ENERGY - NORTH WINDOW (Miami)
METAL FREESTANDING

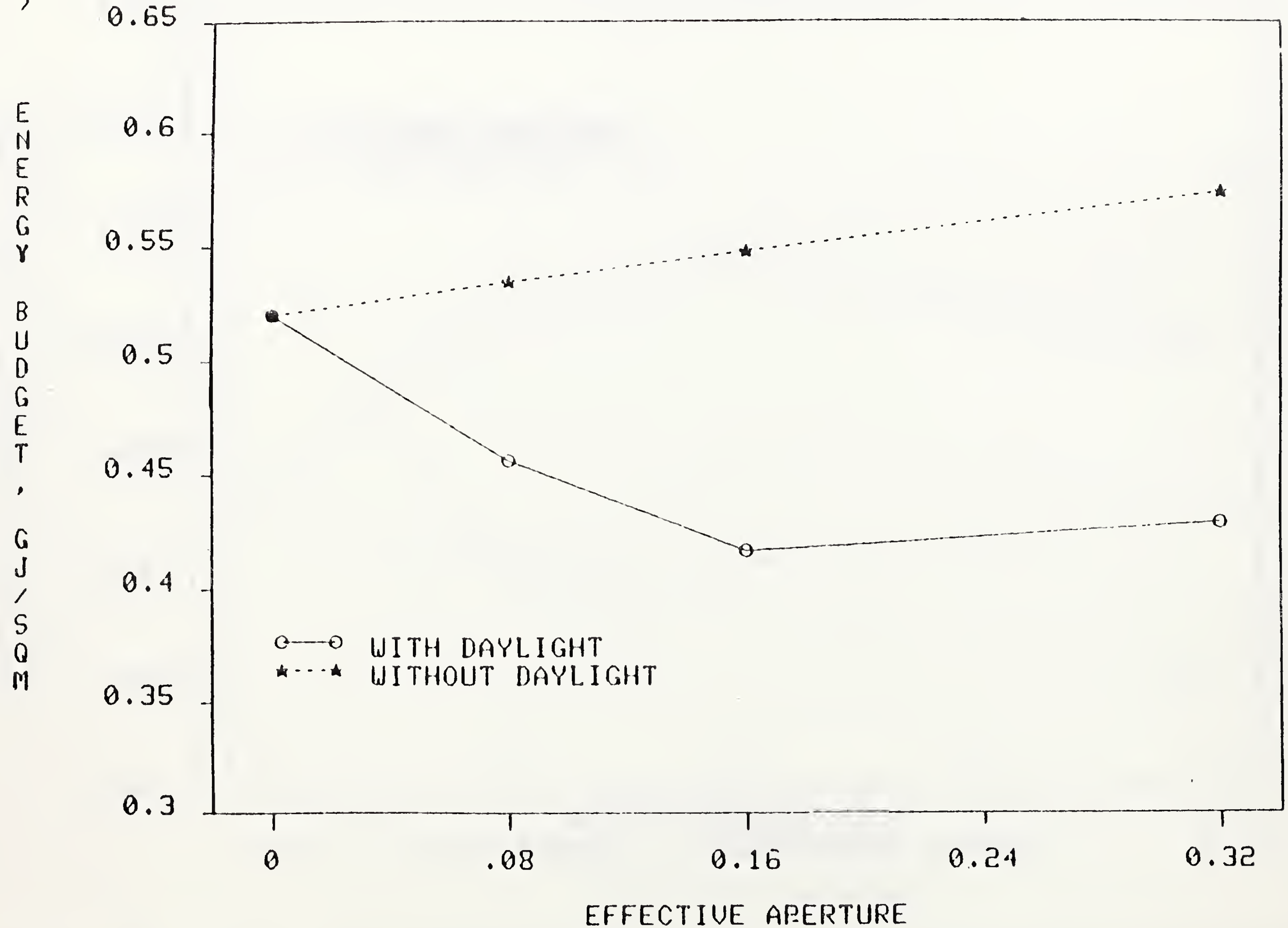


Figure 54. TOTAL ENERGY - SKYLIGHTS (Miami) METAL ATTACHED

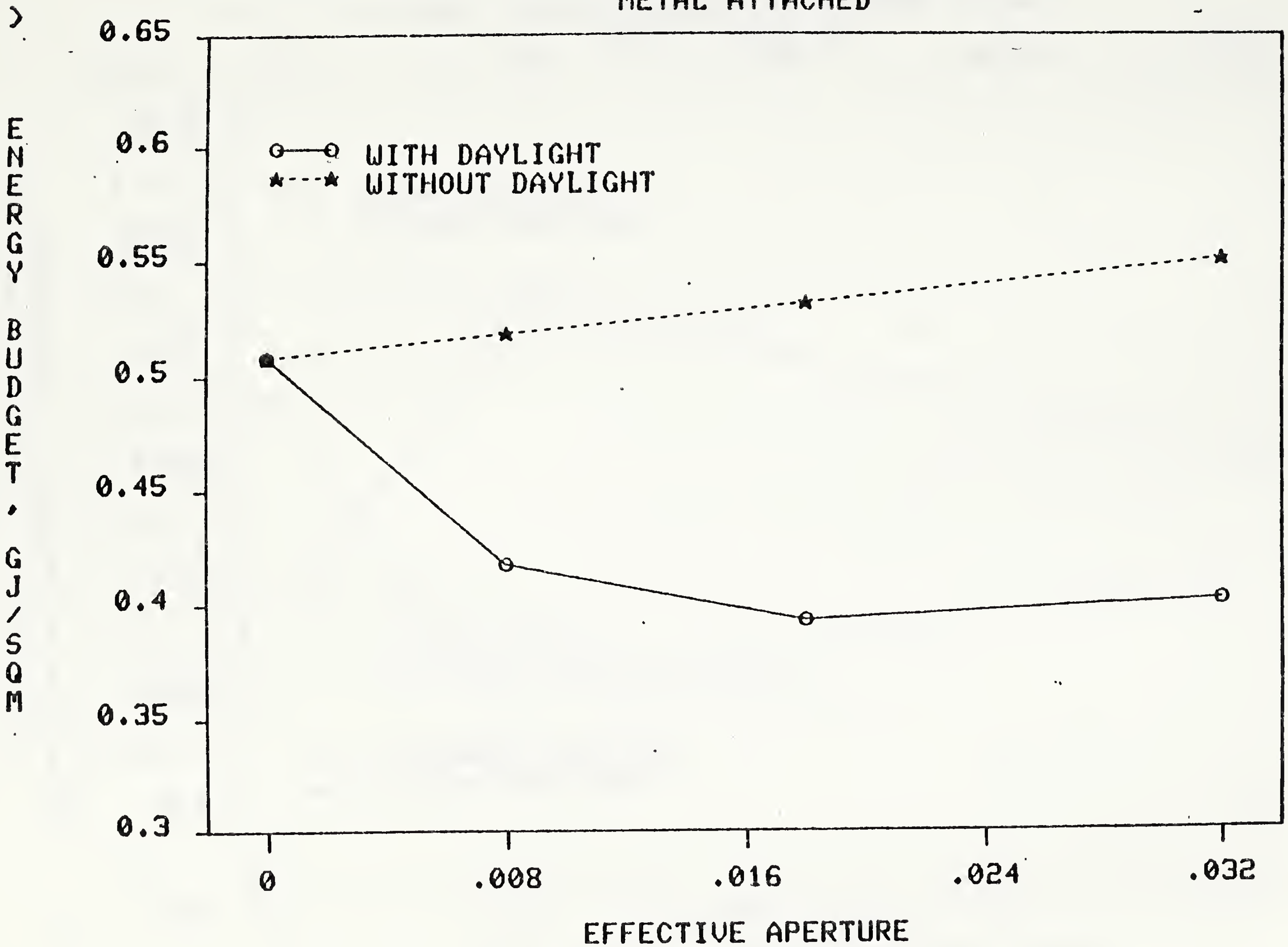


Figure 55. TOTAL ENERGY - SOUTH SAWTOOTH (Miami)
METAL ATTACHED

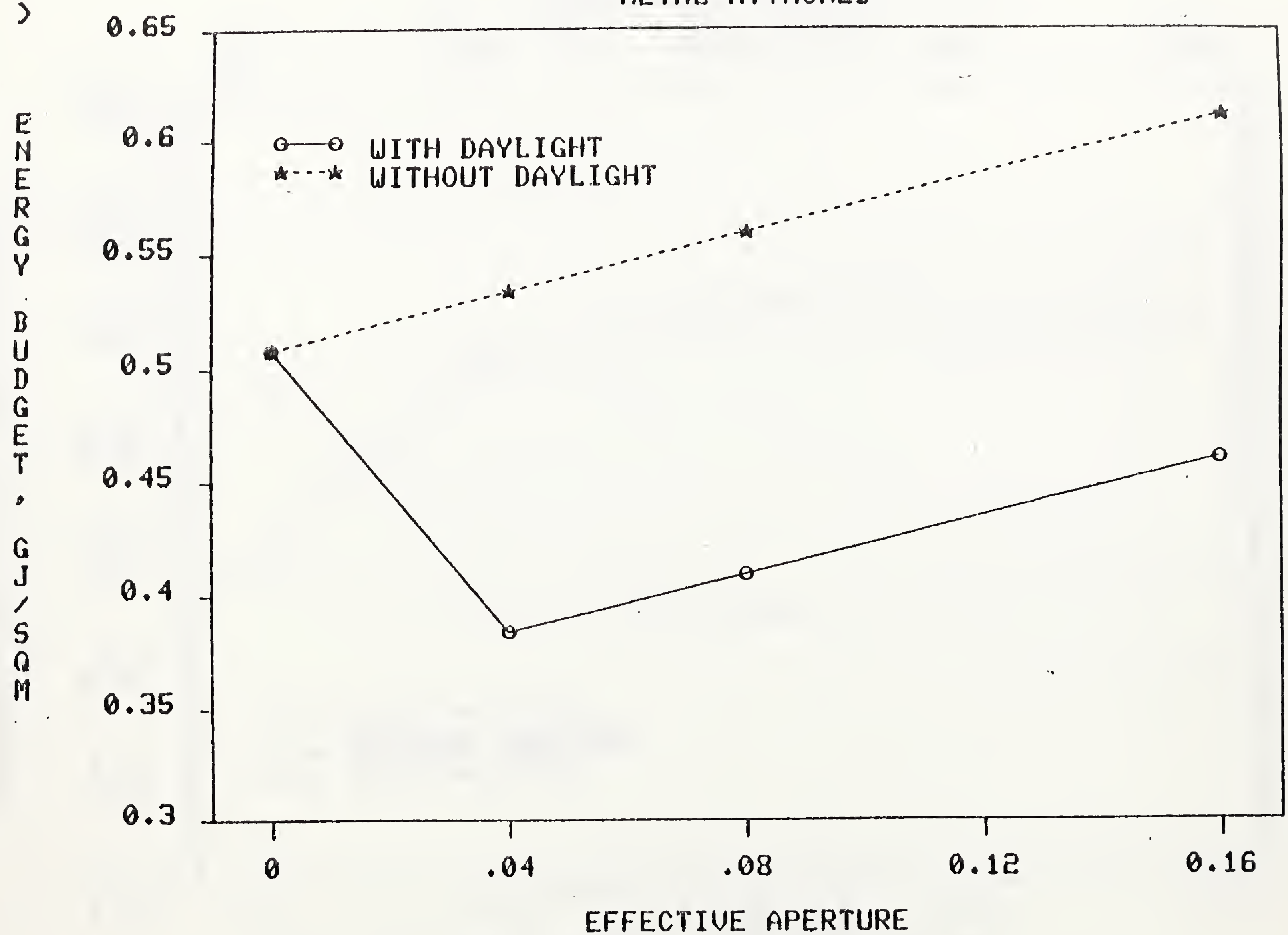


Figure 56. TOTAL ENERGY - NORTH SAWTOOTH (Miami)
METAL ATTACHED

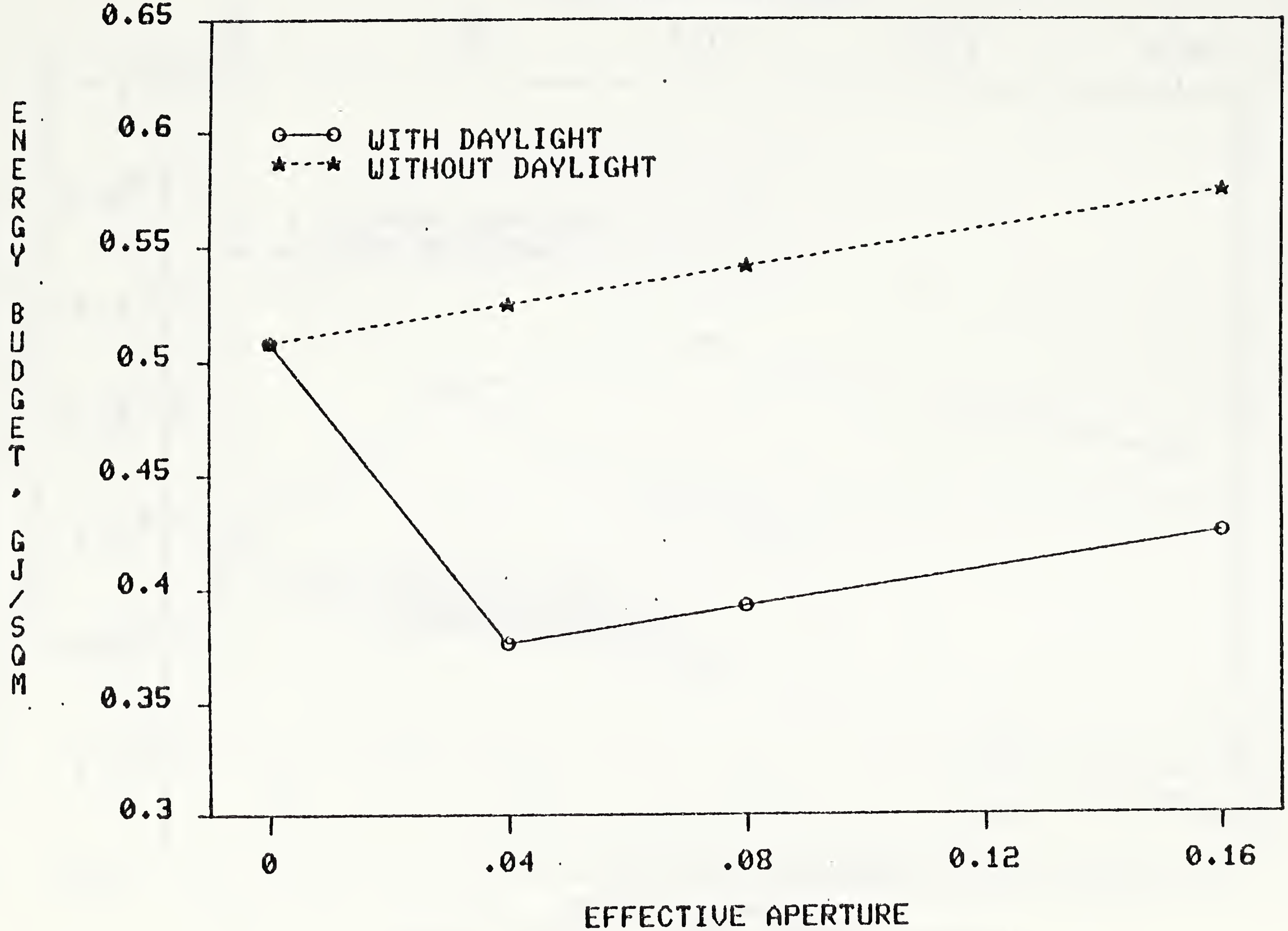


Figure 57. TOTAL ENERGY - SOUTH WINDOW (Miami)
METAL ATTACHED

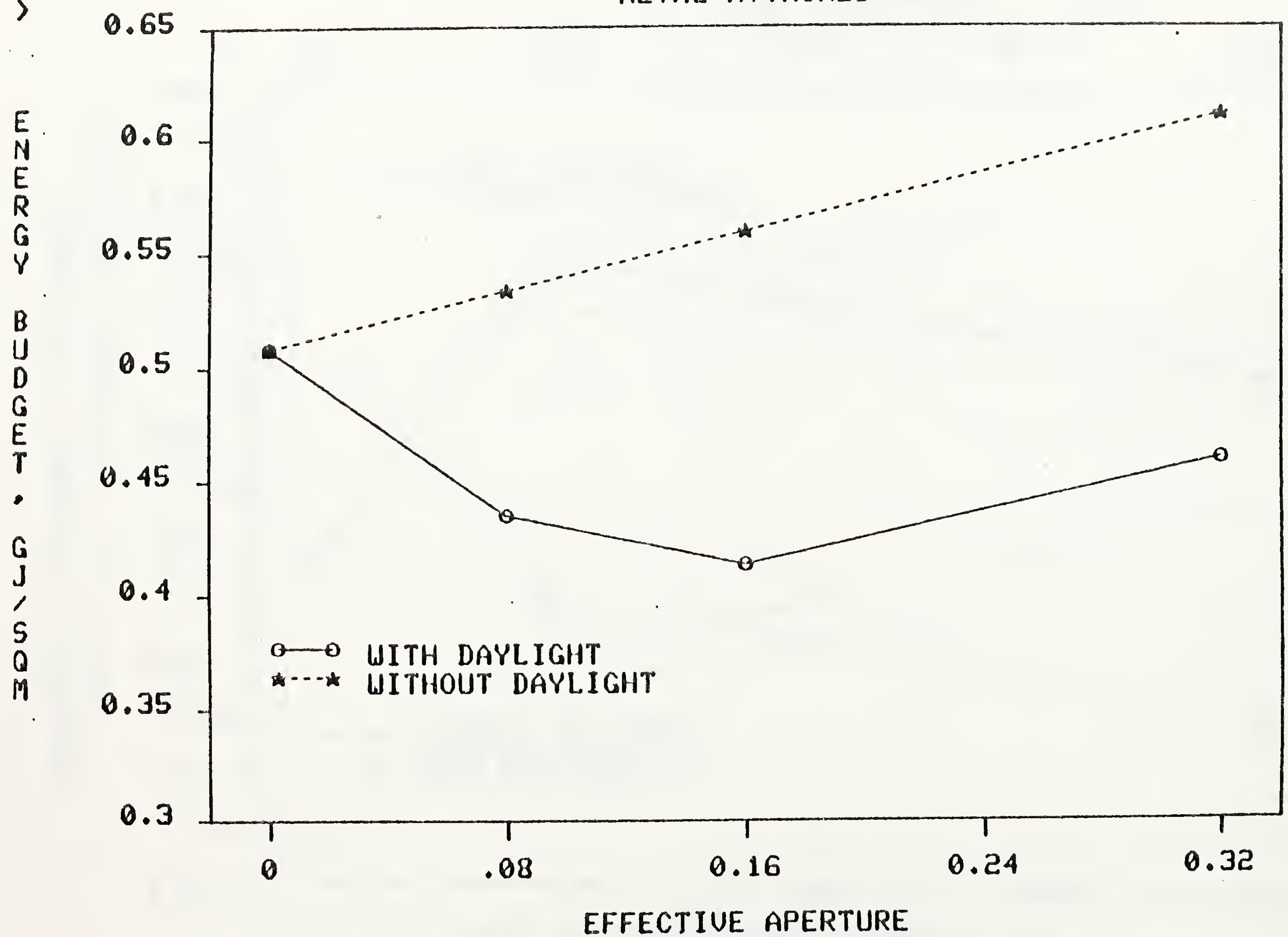


Figure 58. TOTAL ENERGY - NORTH WINDOW (Miami)
METAL ATTACHED

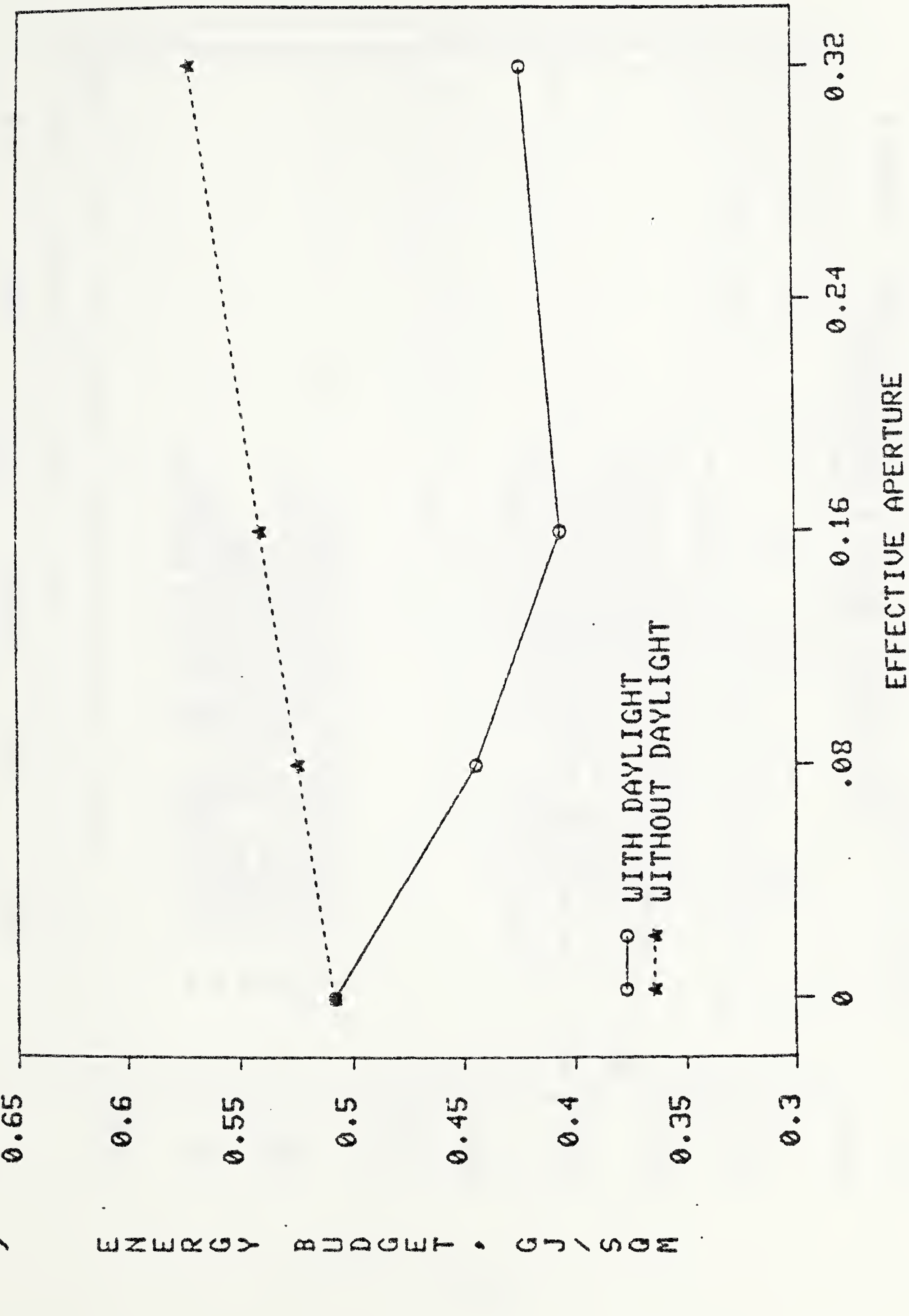


Figure 59. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
SKYLIGHTS, BRICK FREESTANDING

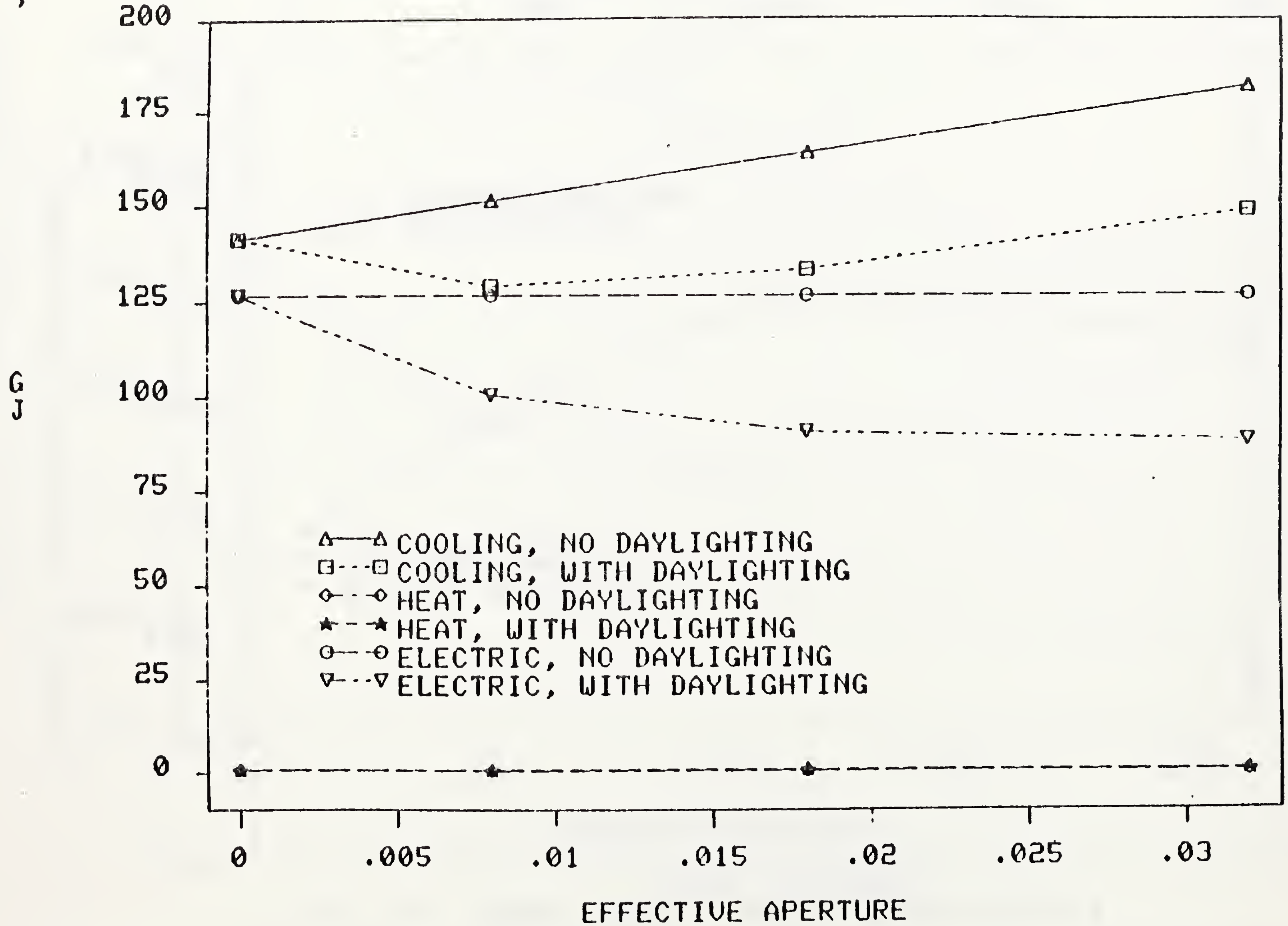


Figure 60. ANNUAL COOLING, HEATING AND ELECTRIC LOADS (Miami)
SOUTH SAWTOOTH, BRICK FREESTANDING

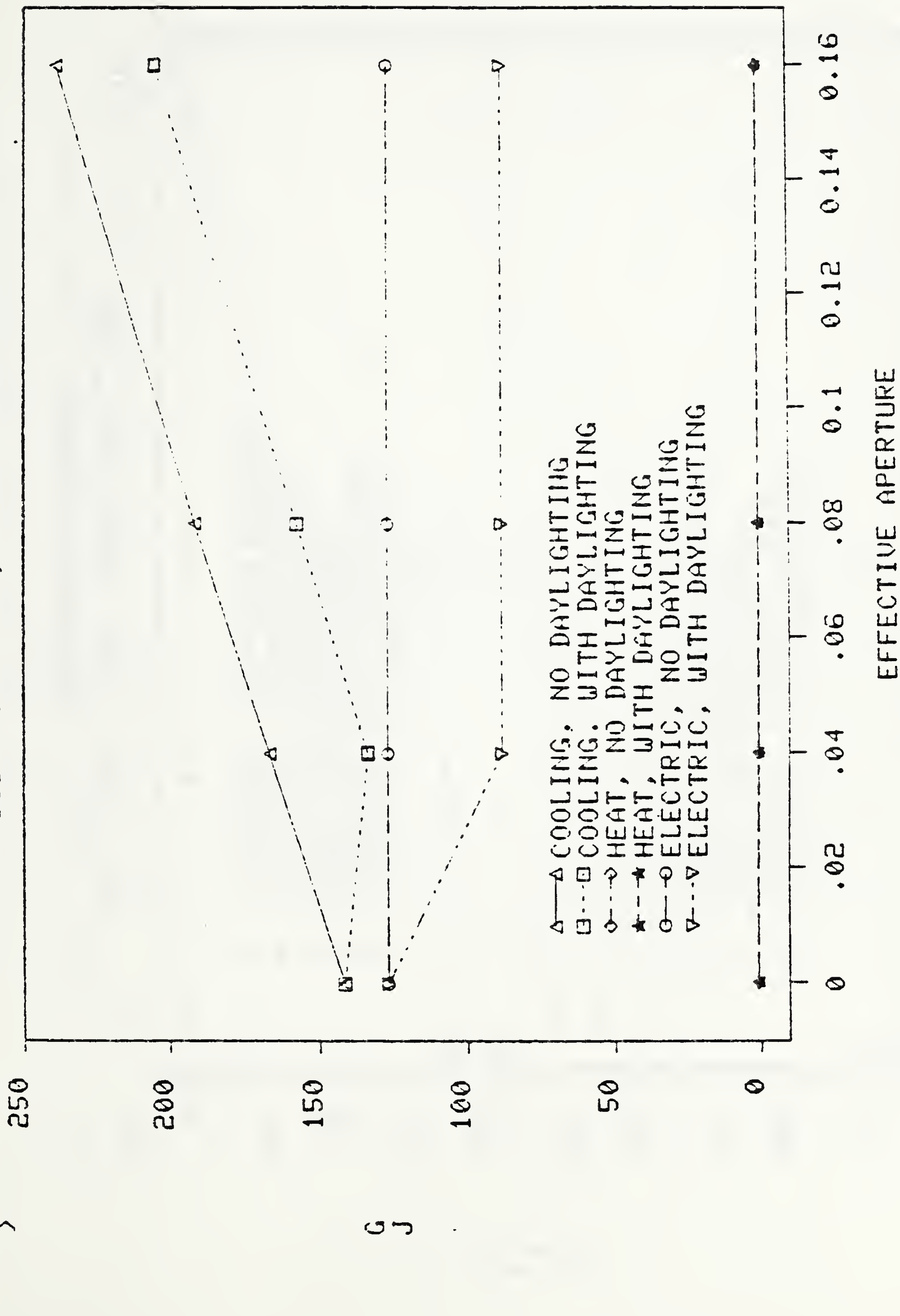


Figure 61. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
NORTH SAWTOOTH, BRICK FREESTANDING

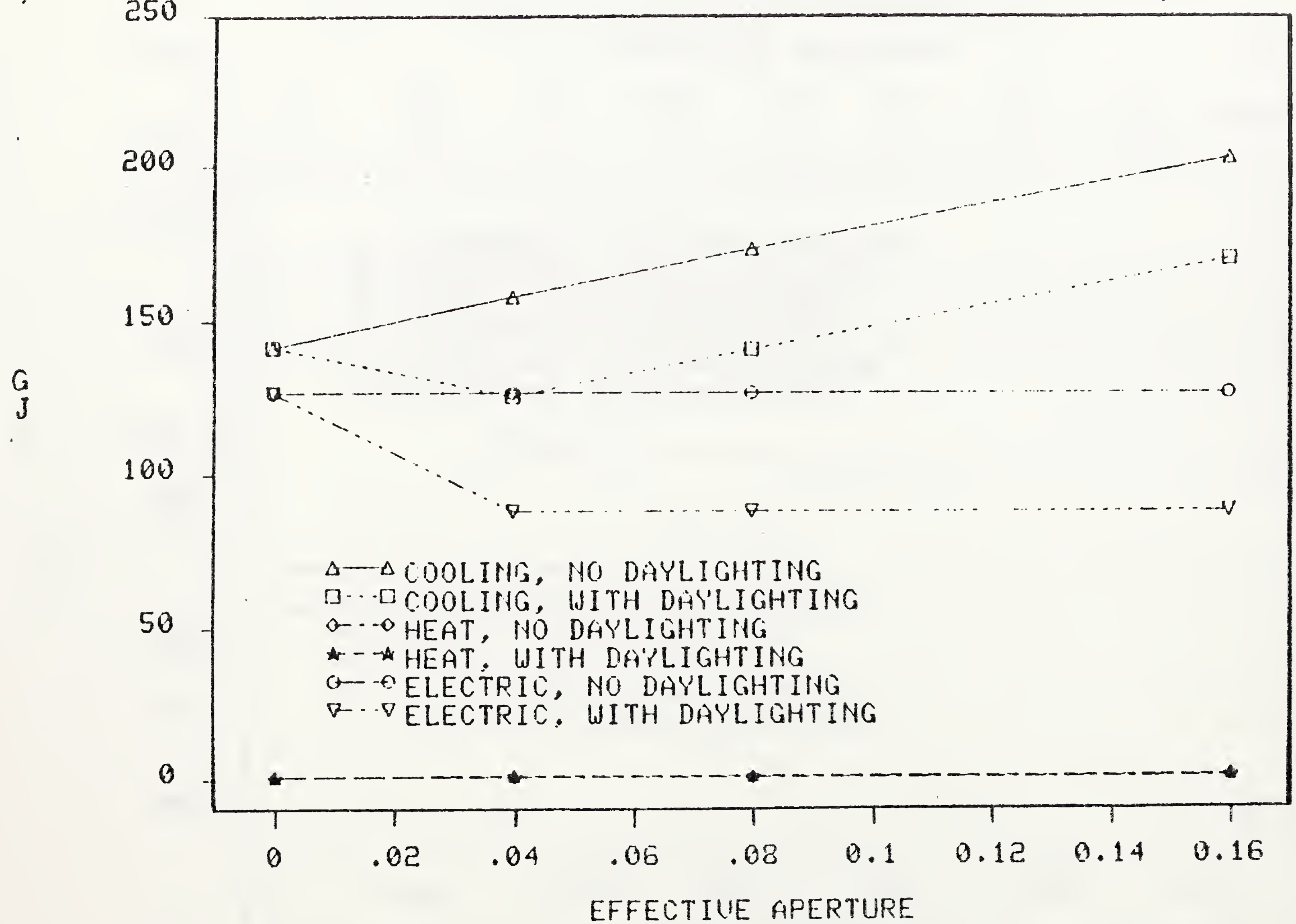


Figure 62. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
SOUTH WINDOW. BRICK FREESTANDING

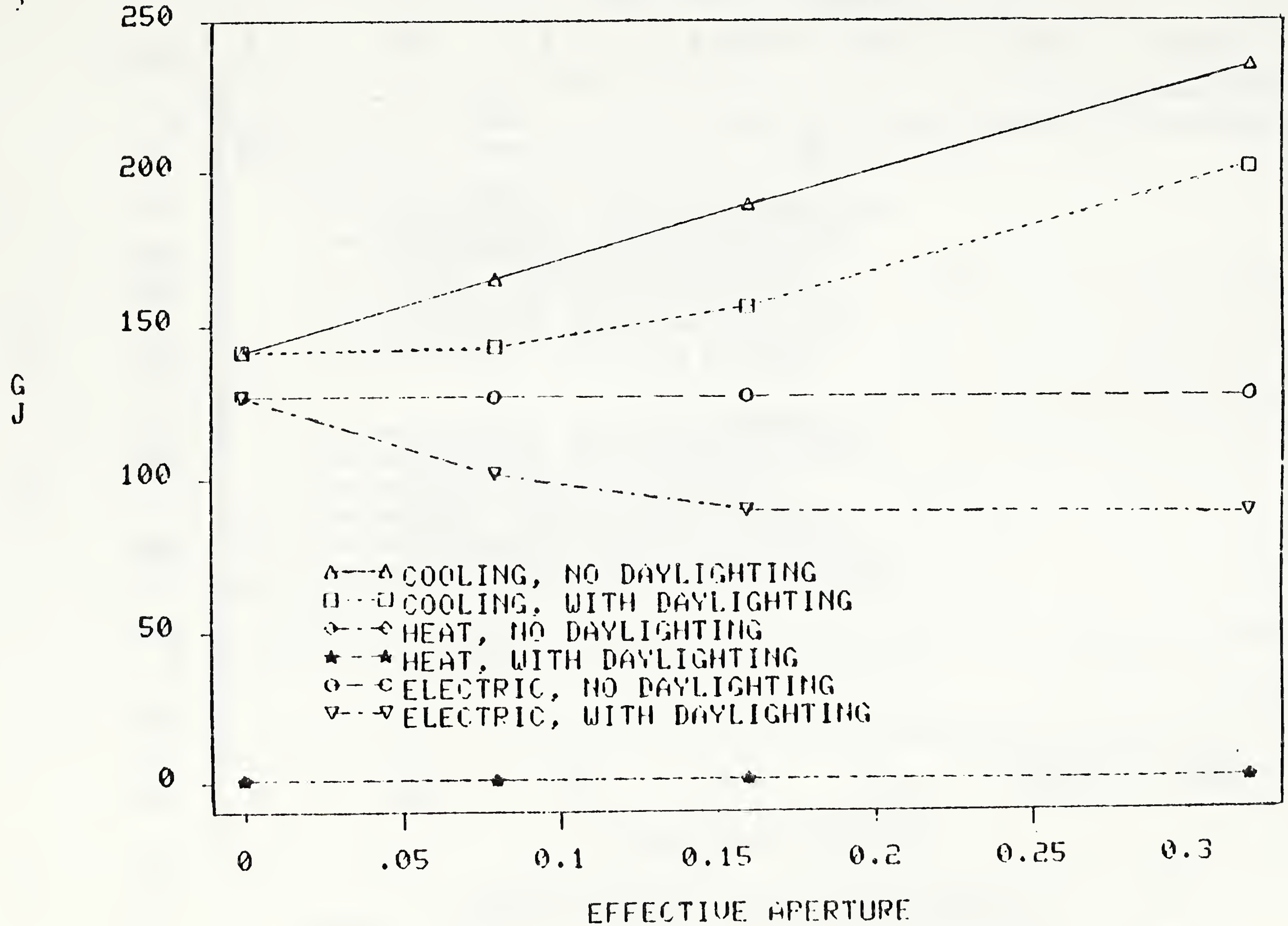


Figure 63. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
NORTH WINDOW, BRICK FREESTANDING

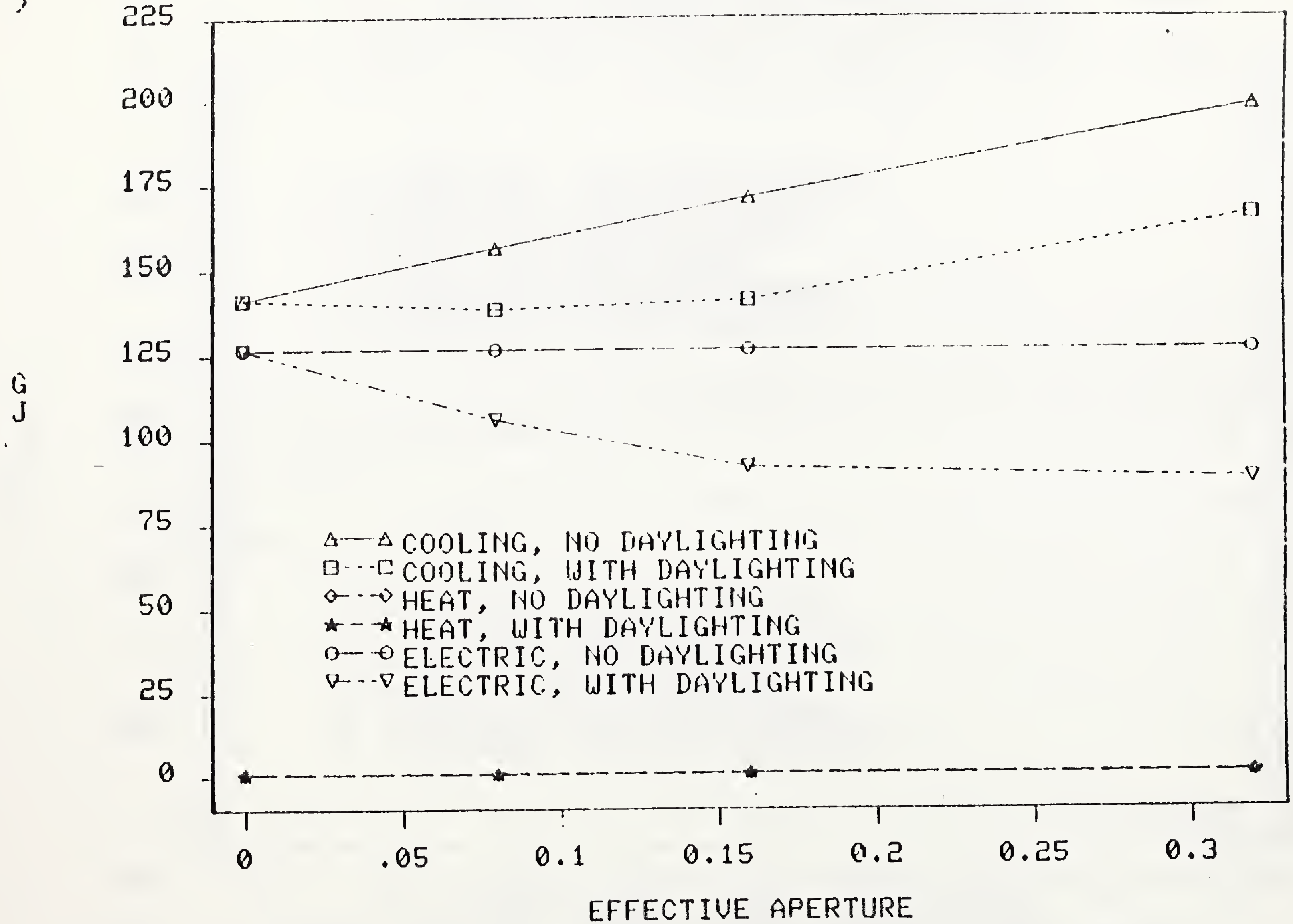


Figure 64. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
SKYLIGHTS, BRICK ATTACHED

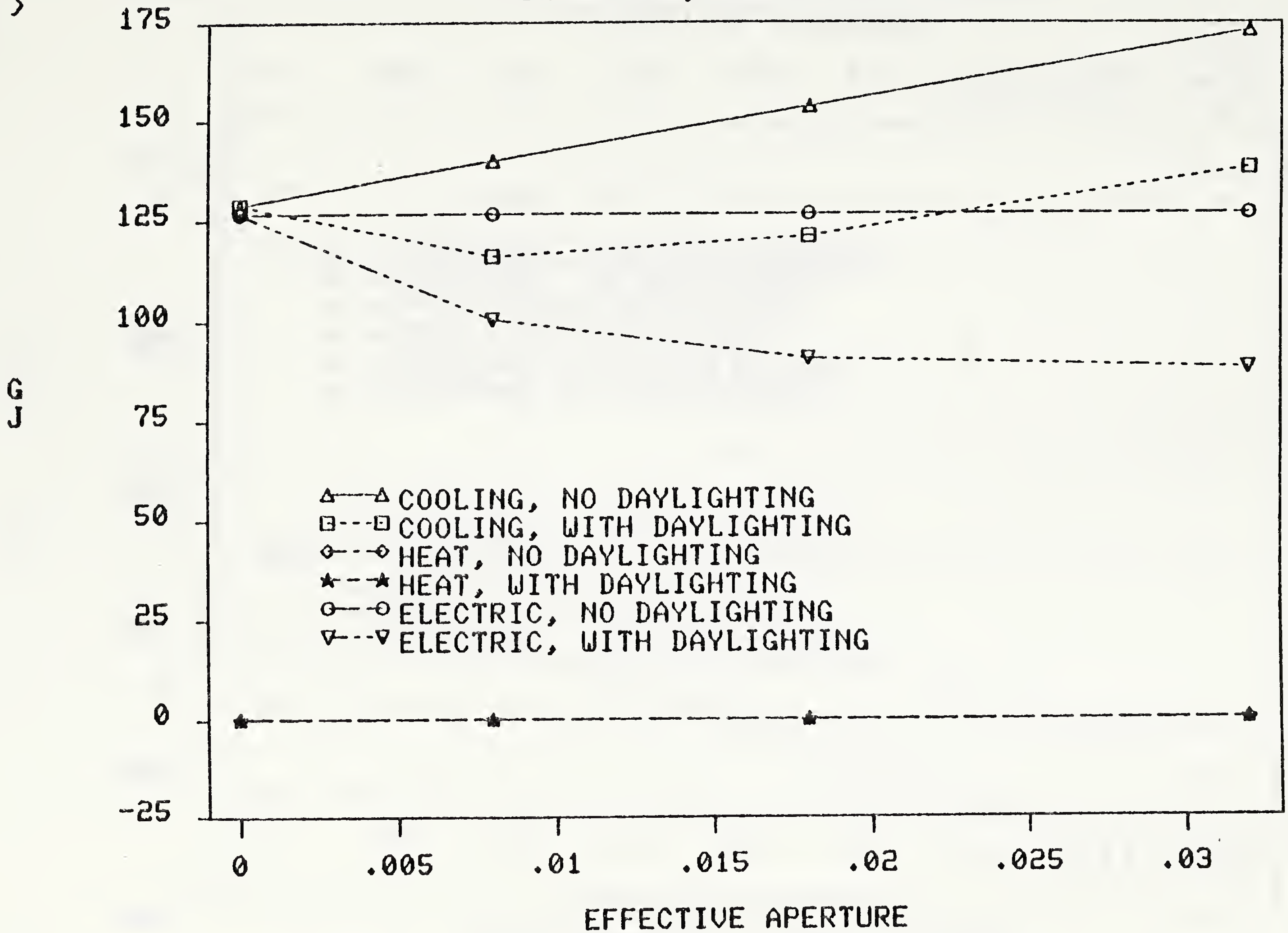


Figure 65. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami) SOUTH SAWTOOTH, BRICK ATTACHED

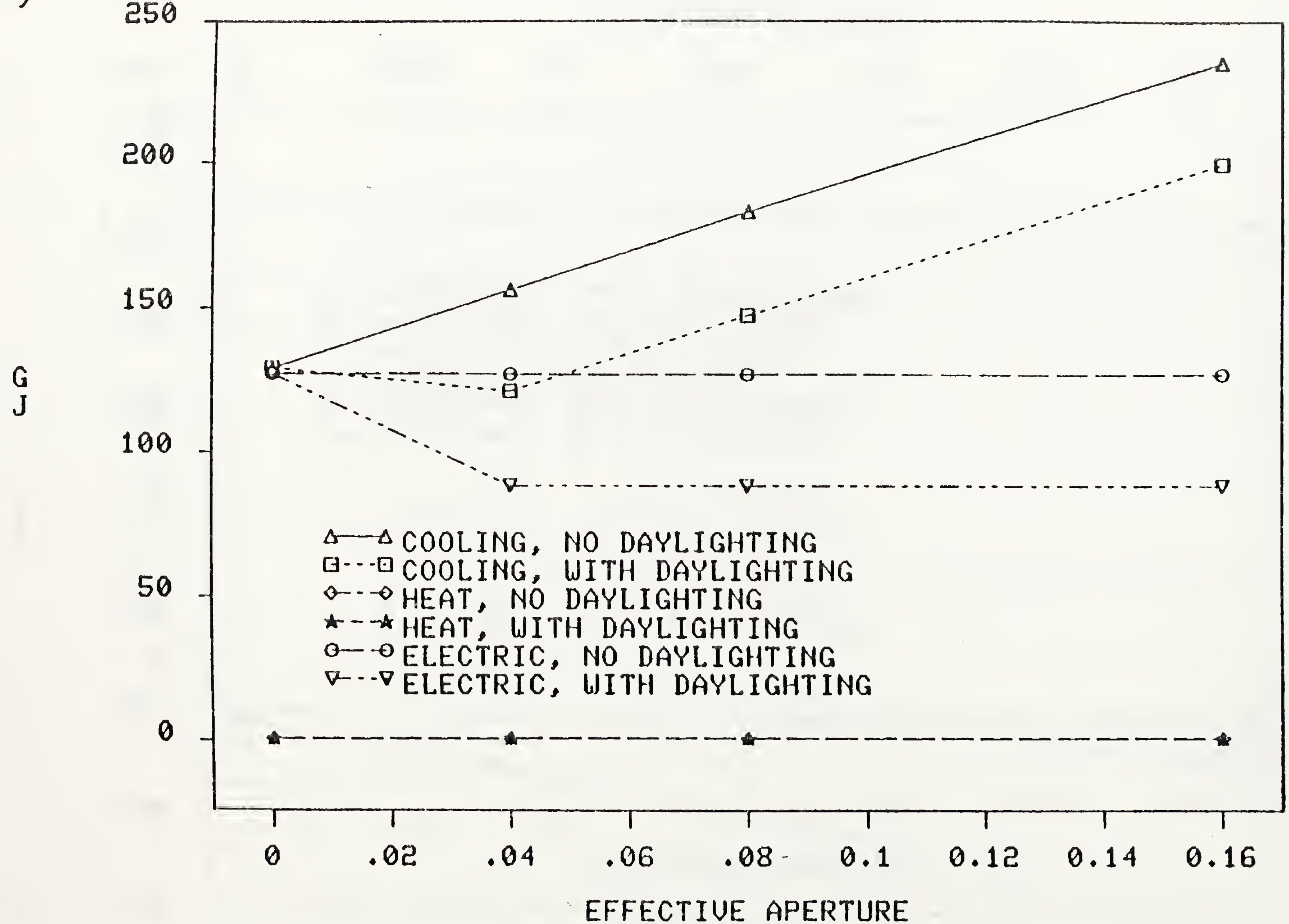


Figure 66. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
NORTH SAWTOOTH, BRICK ATTACHED

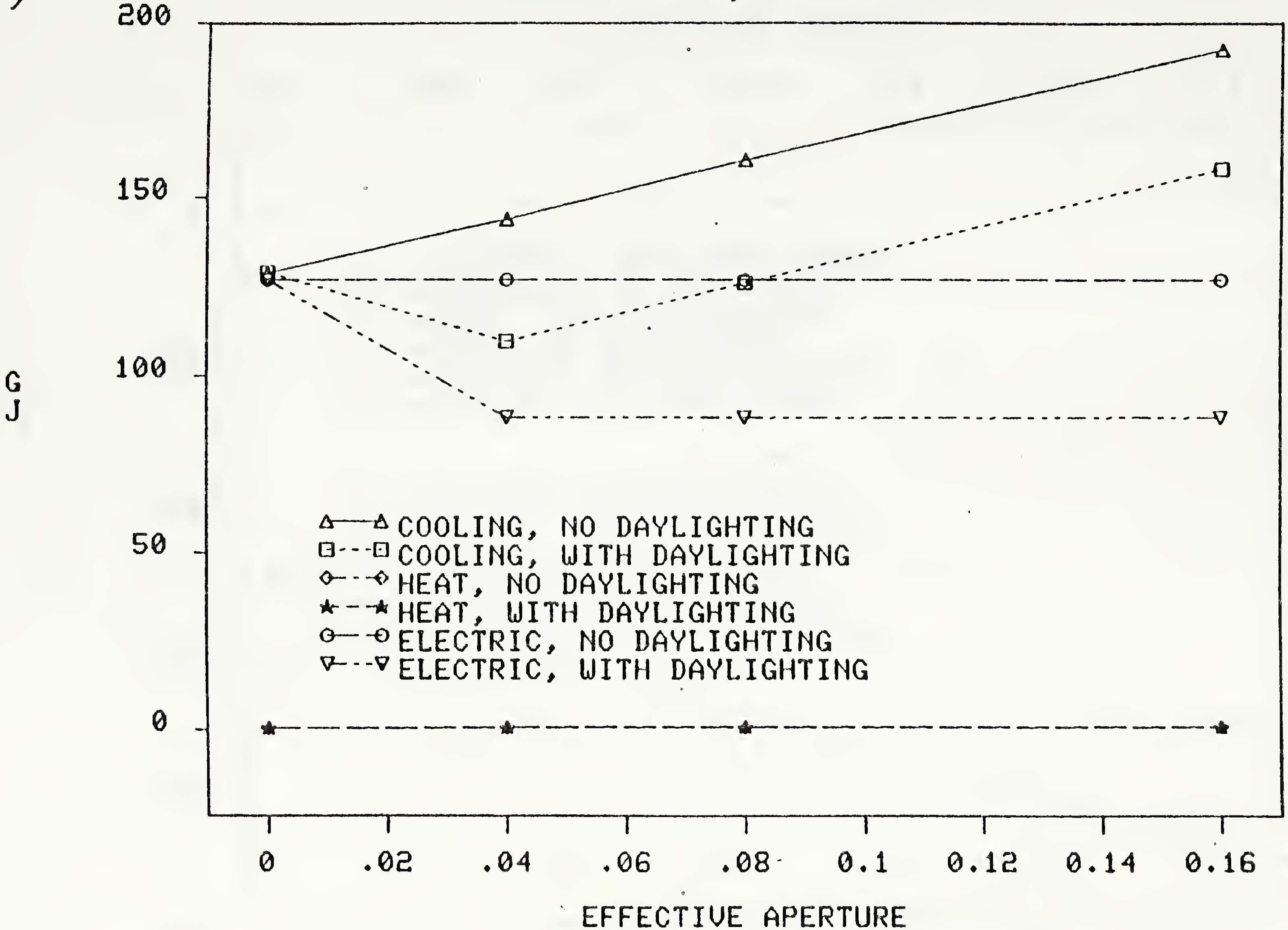


Figure 67. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
SOUTH WINDOW, BRICK ATTACHED

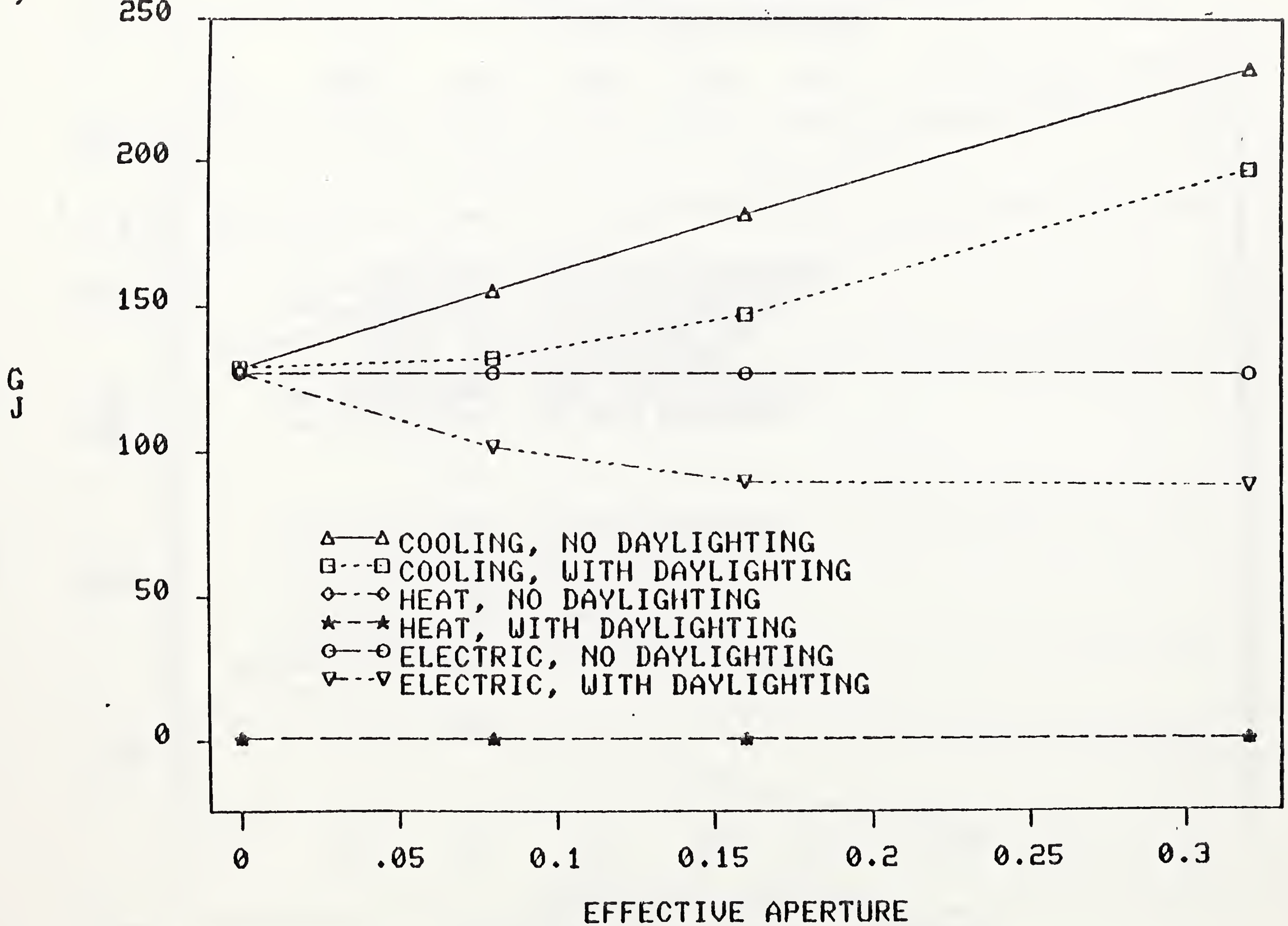


Figure 68. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami) NORTH WINDOW, BRICK ATTACHED

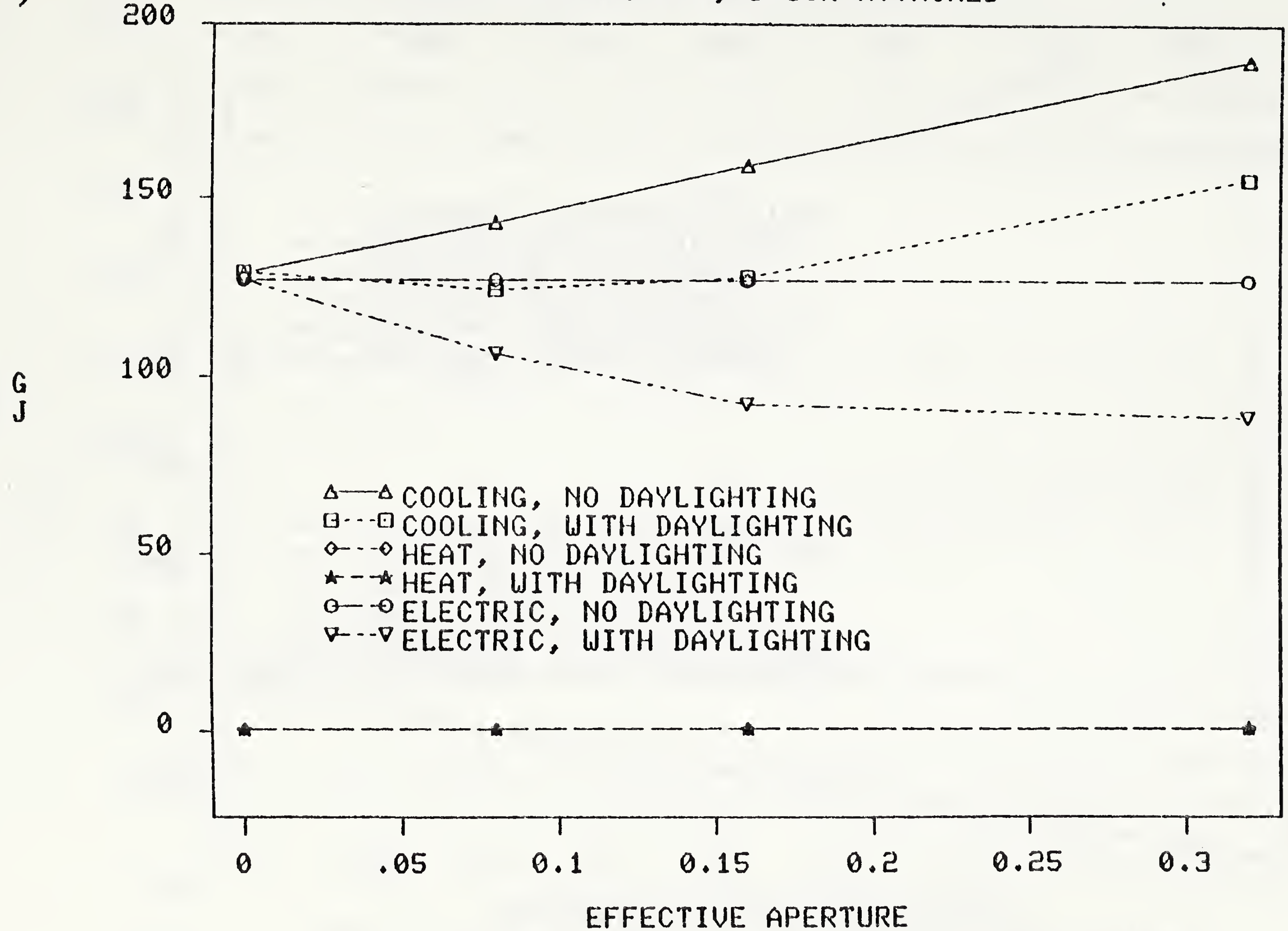


Figure 69. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
SKYLIGHTS, METAL FREESTANDING

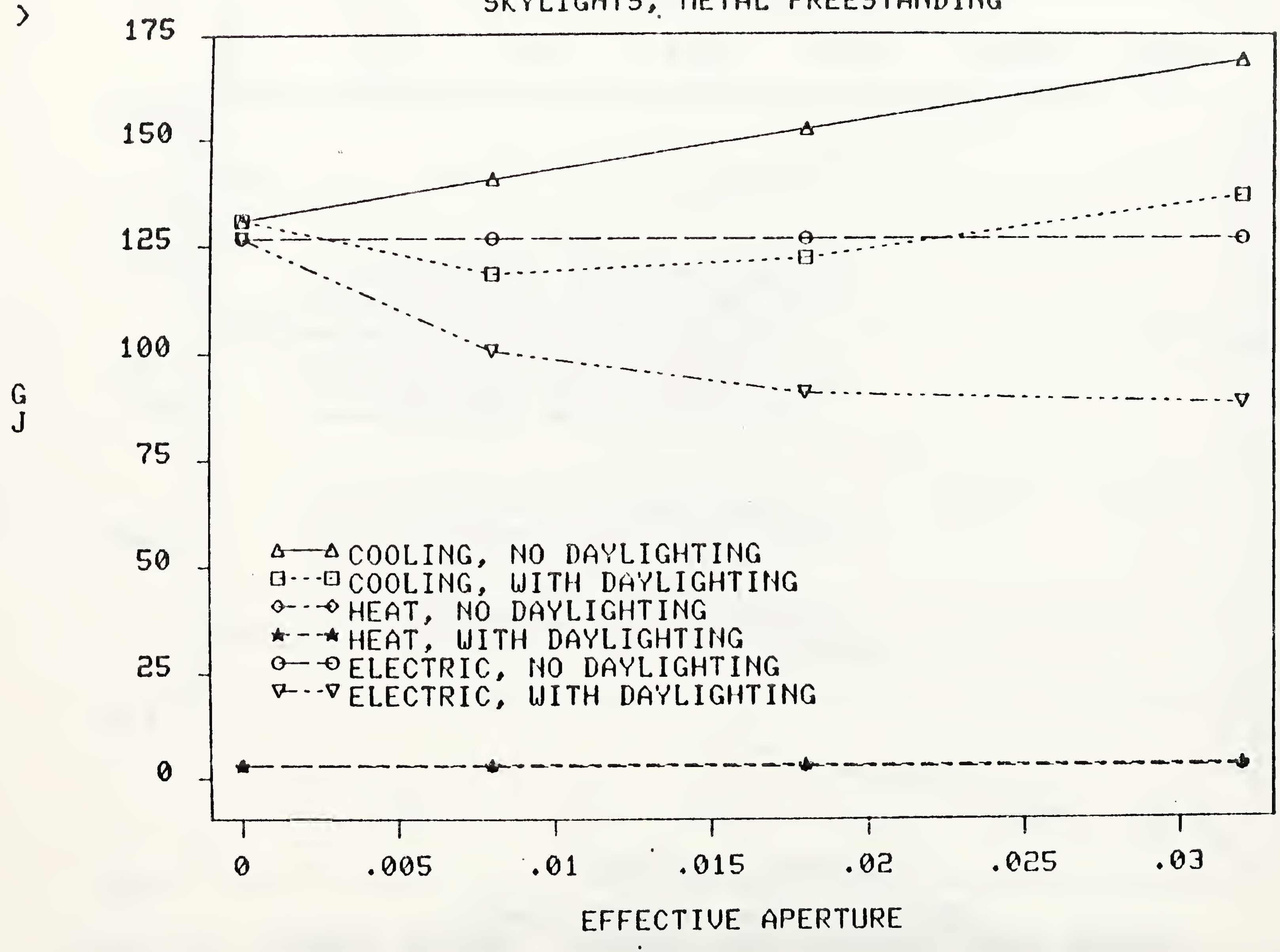


Figure 70. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
SOUTH SAWTOOTH, METAL FREESTANDING

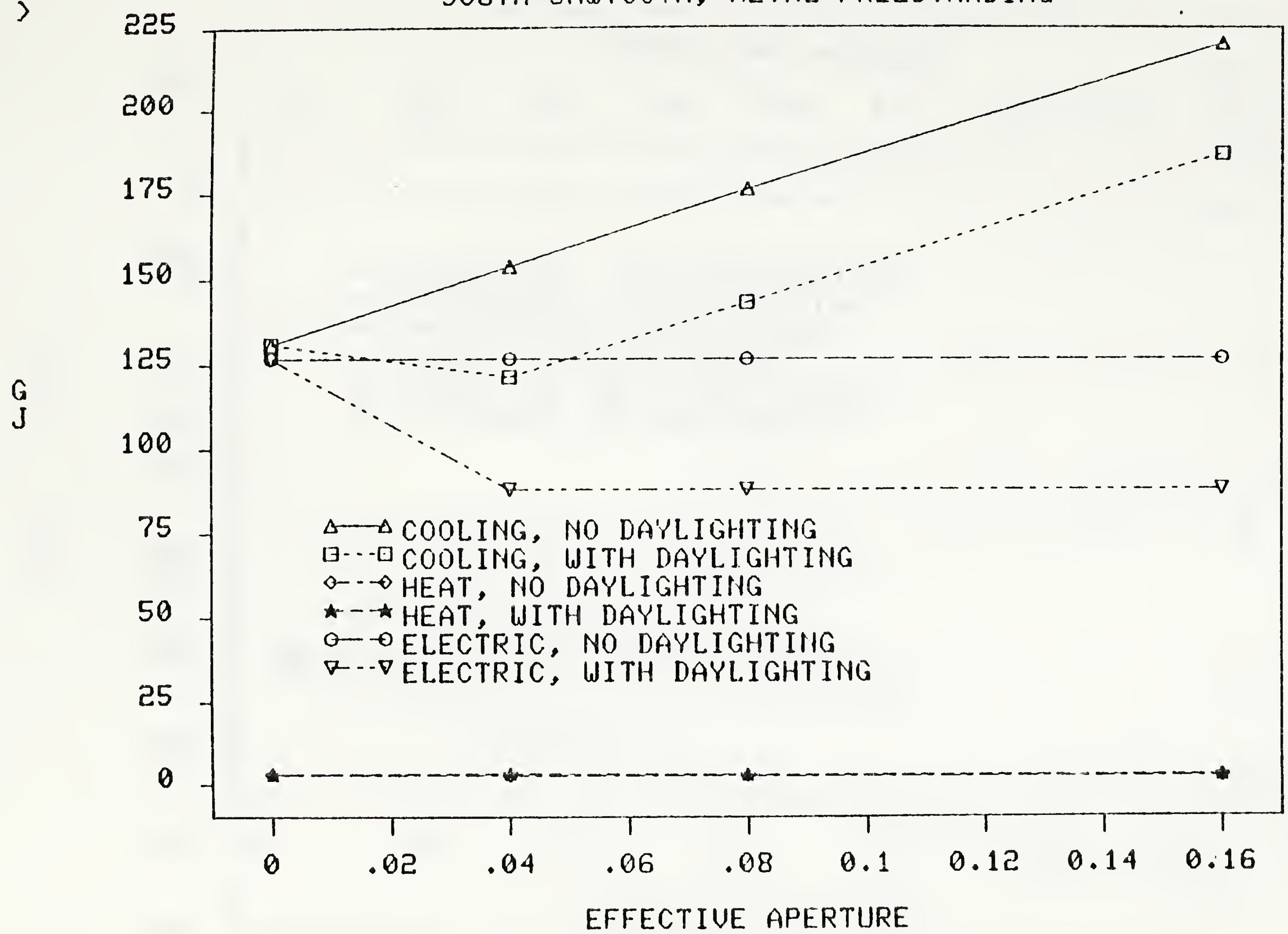


Figure 71. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
NORTH SAWTOOTH, METAL FREESTANDING

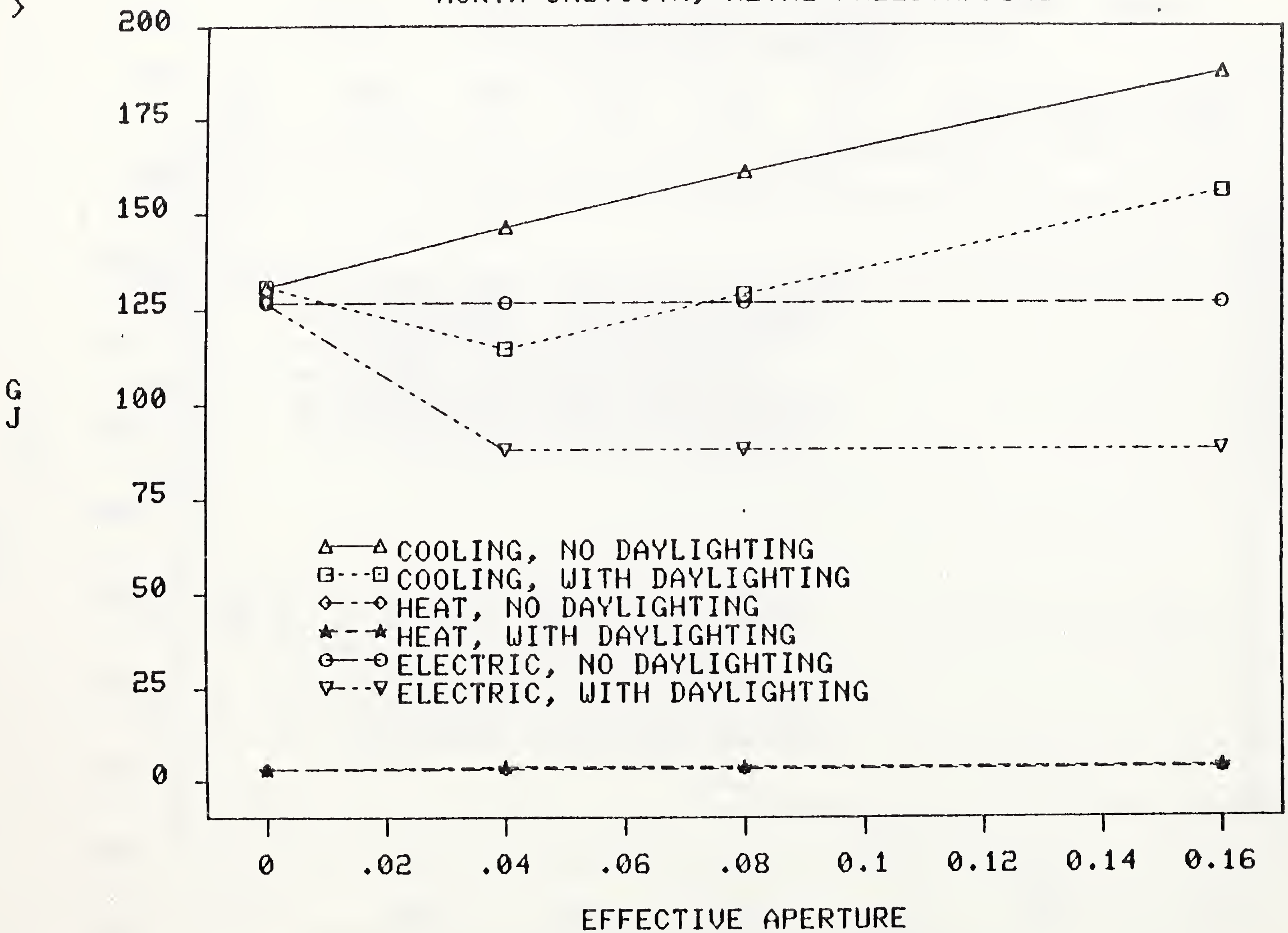


Figure 72. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
SOUTH WINDOW, METAL FREESTANDING

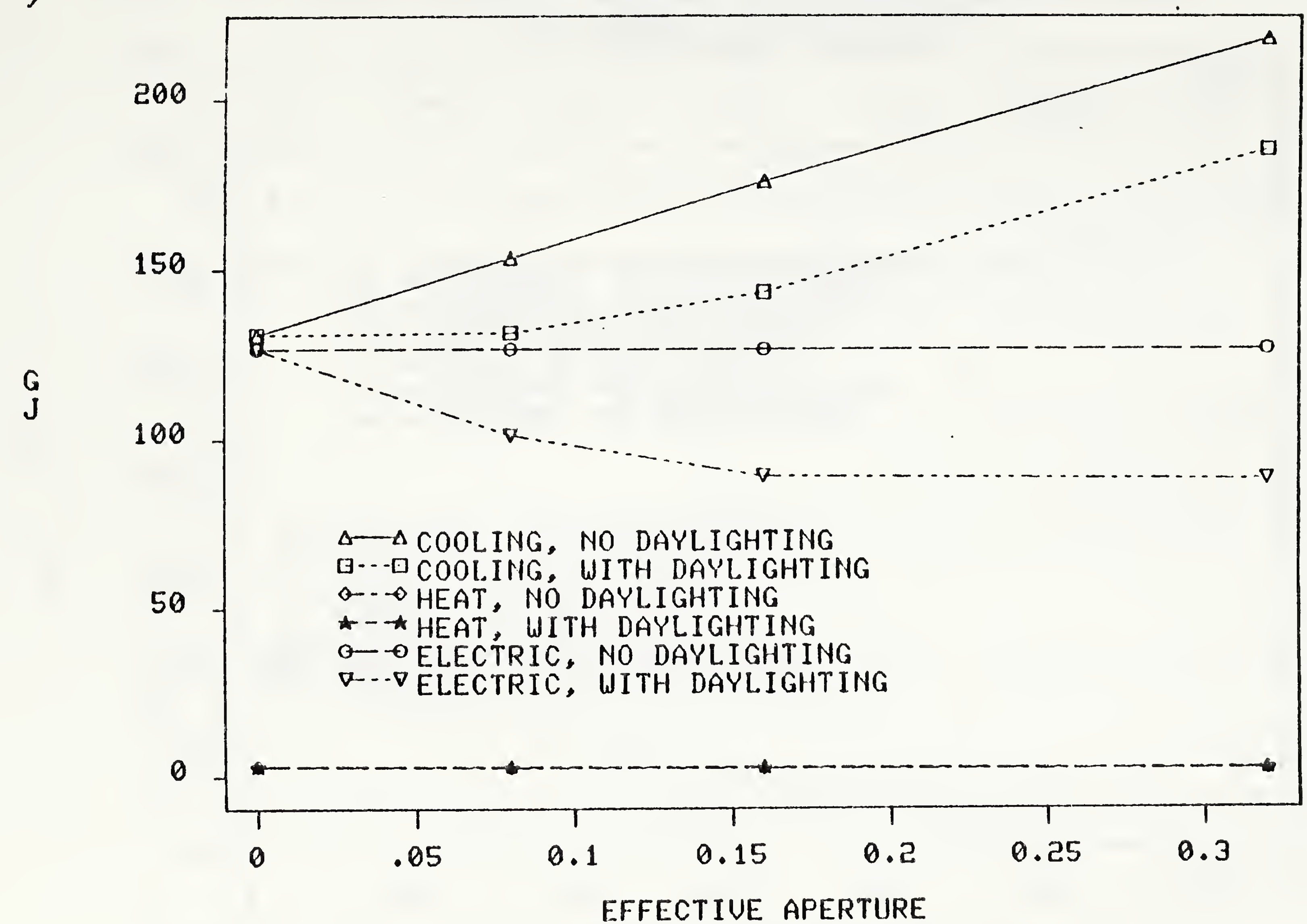


Figure 73. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
NORTH WINDOW, METAL FREESTANDING

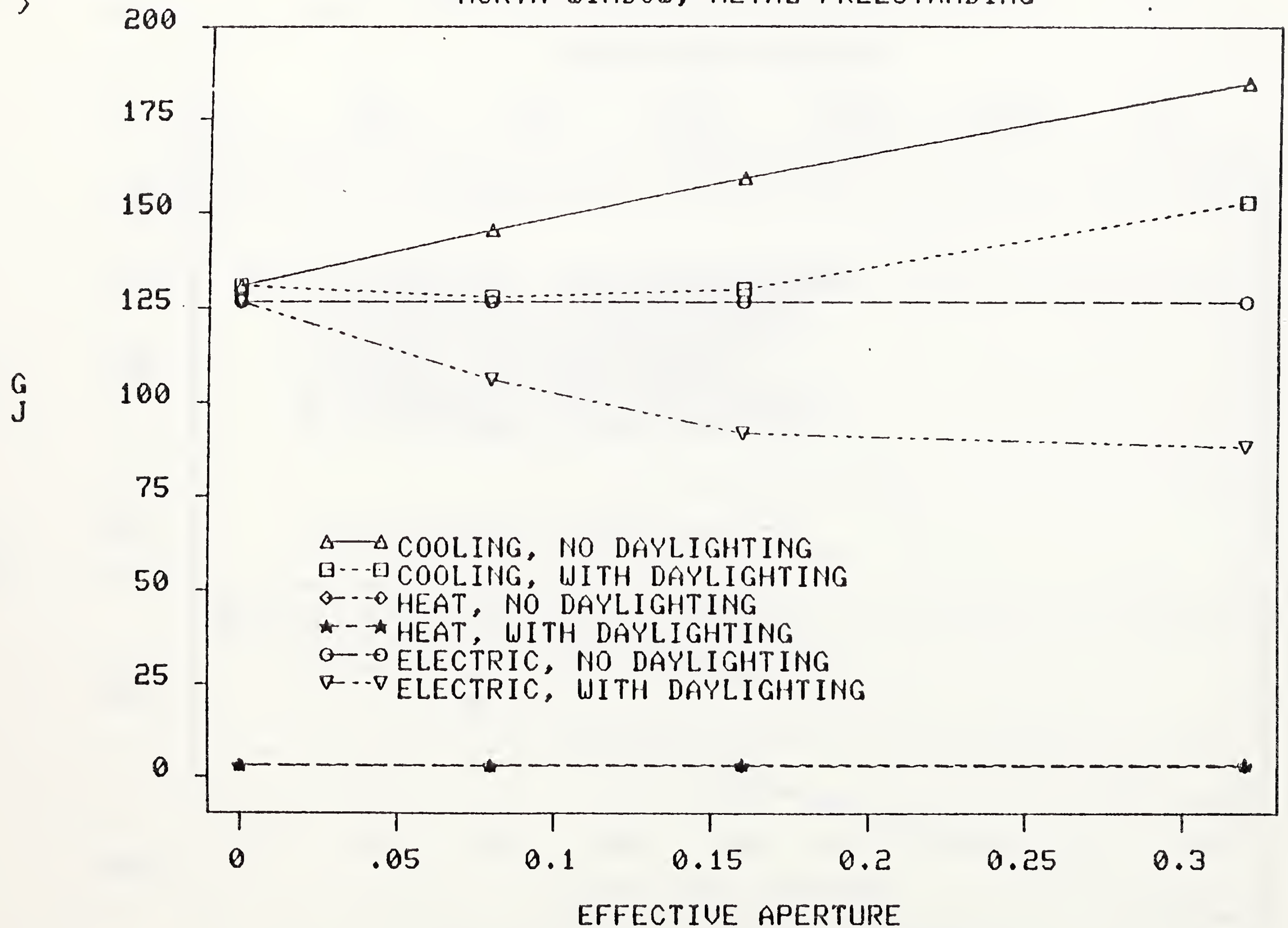


Figure 74. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami) SKYLIGHTS, METAL ATTACHED

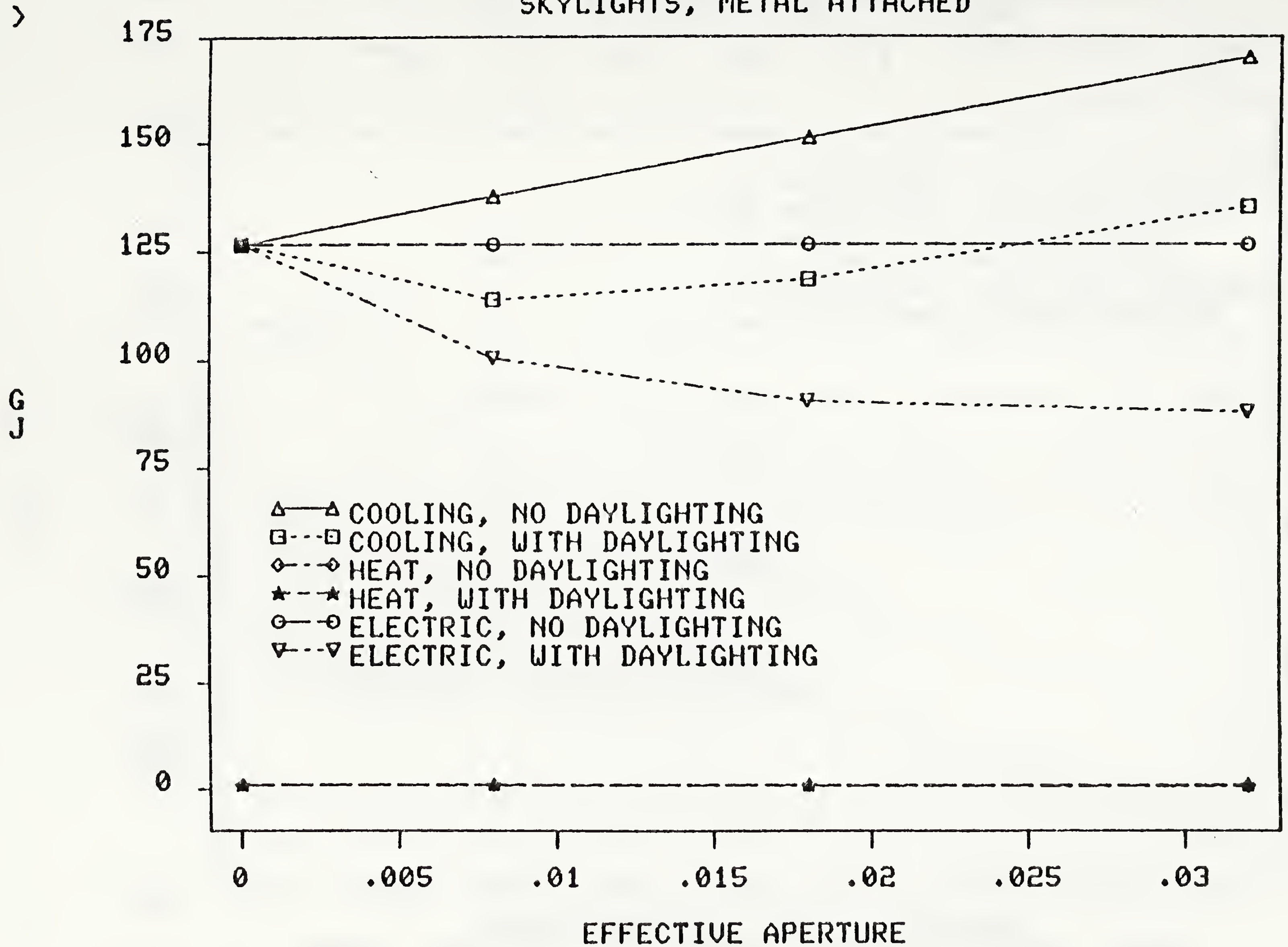


Figure 75. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
SOUTH SAWTOOTH, METAL ATTACHED

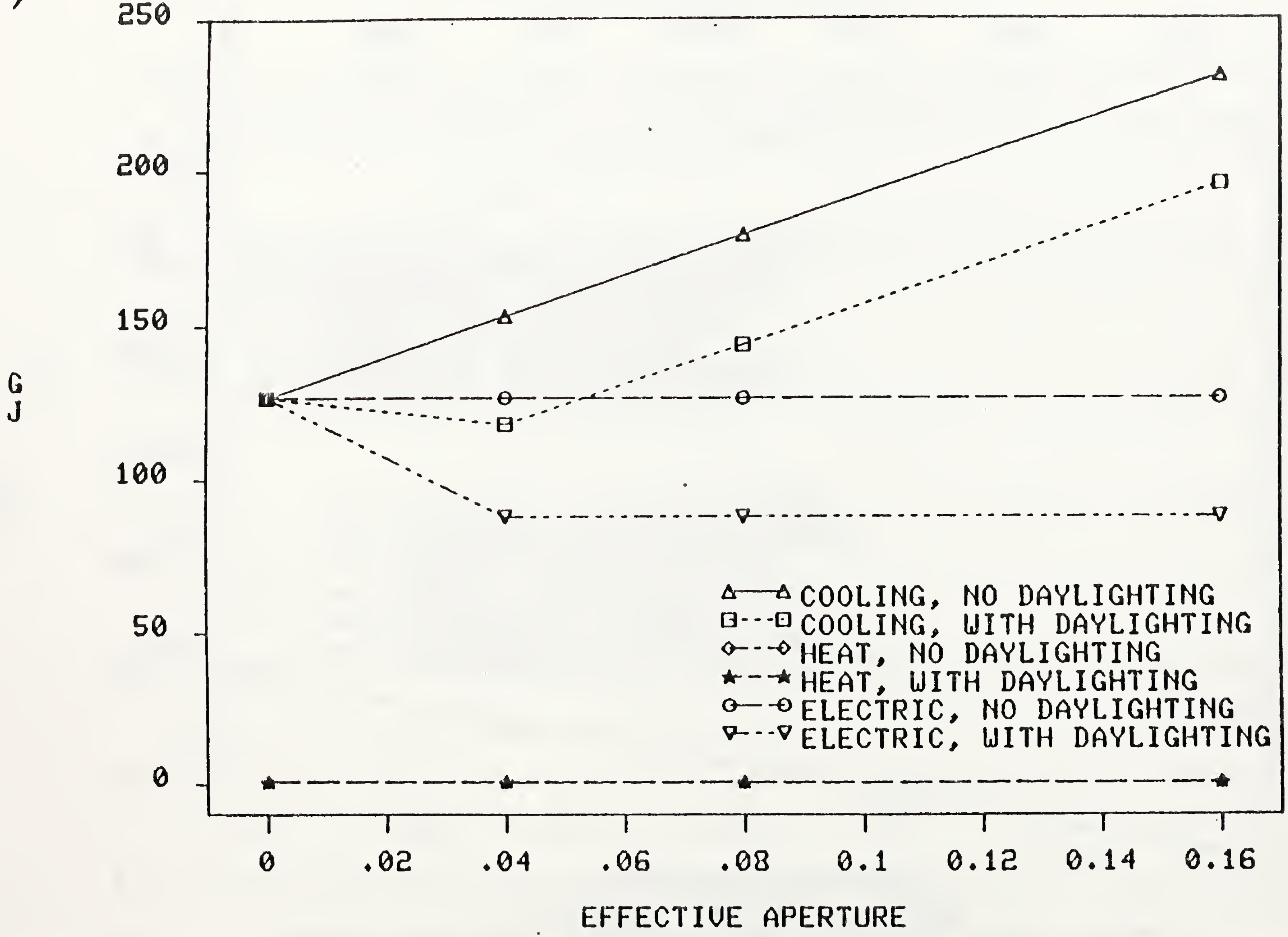


Figure 76. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
NORTH SAWTOOTH, METAL ATTACHED

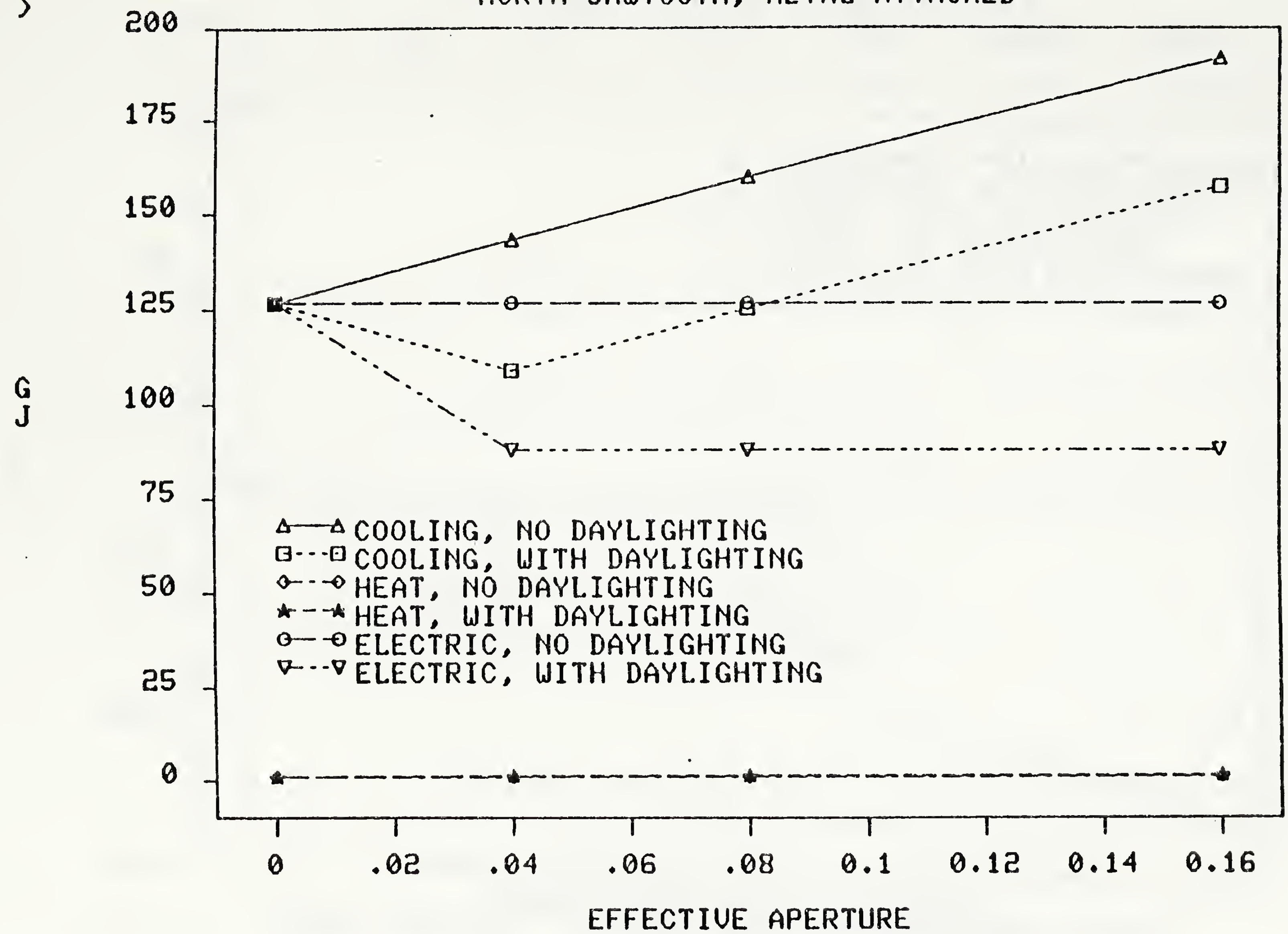


Figure 77. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
SOUTH WINDOW, METAL ATTACHED

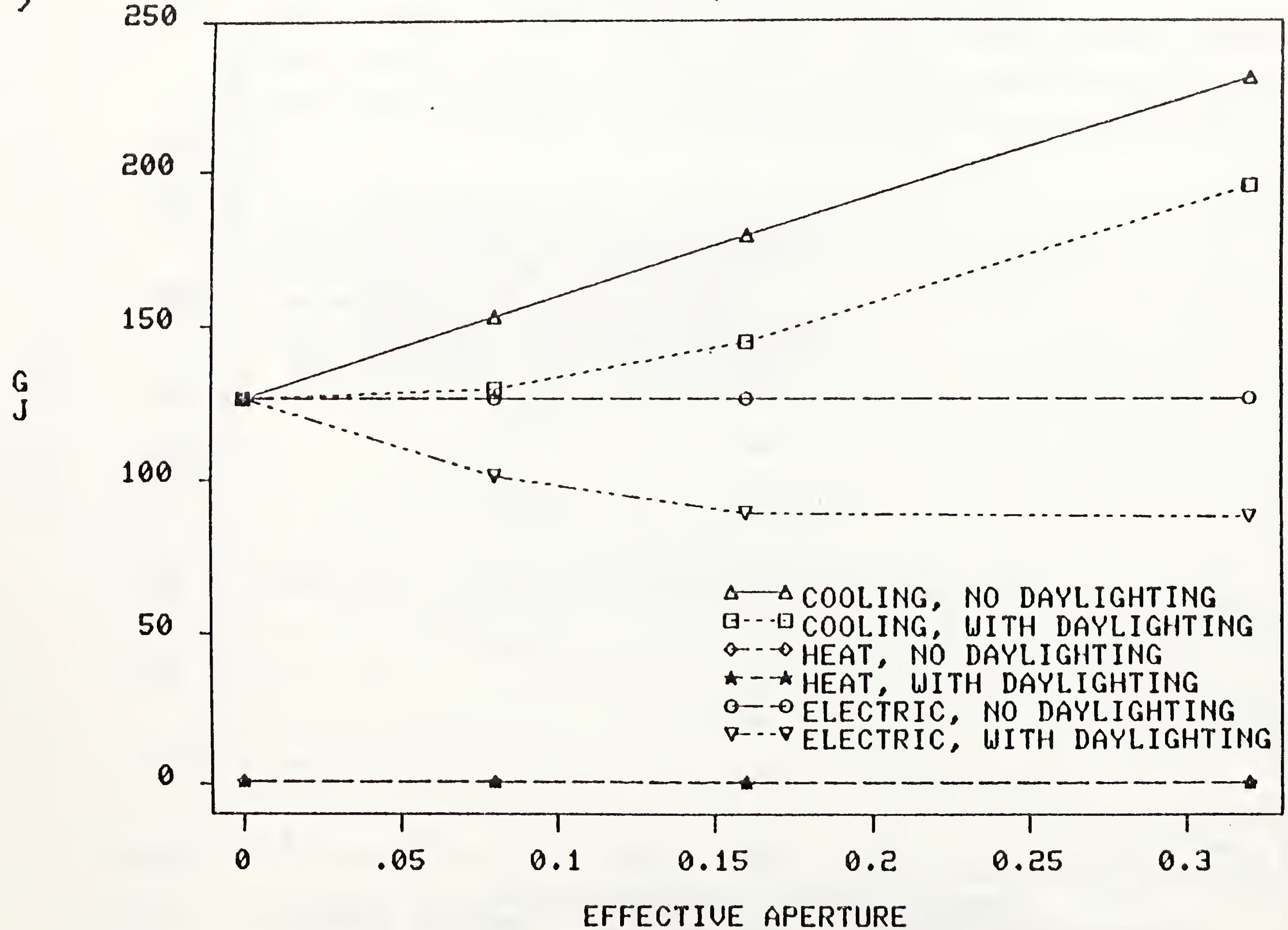


Figure 78. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Miami)
NORTH WINDOW, METAL ATTACHED

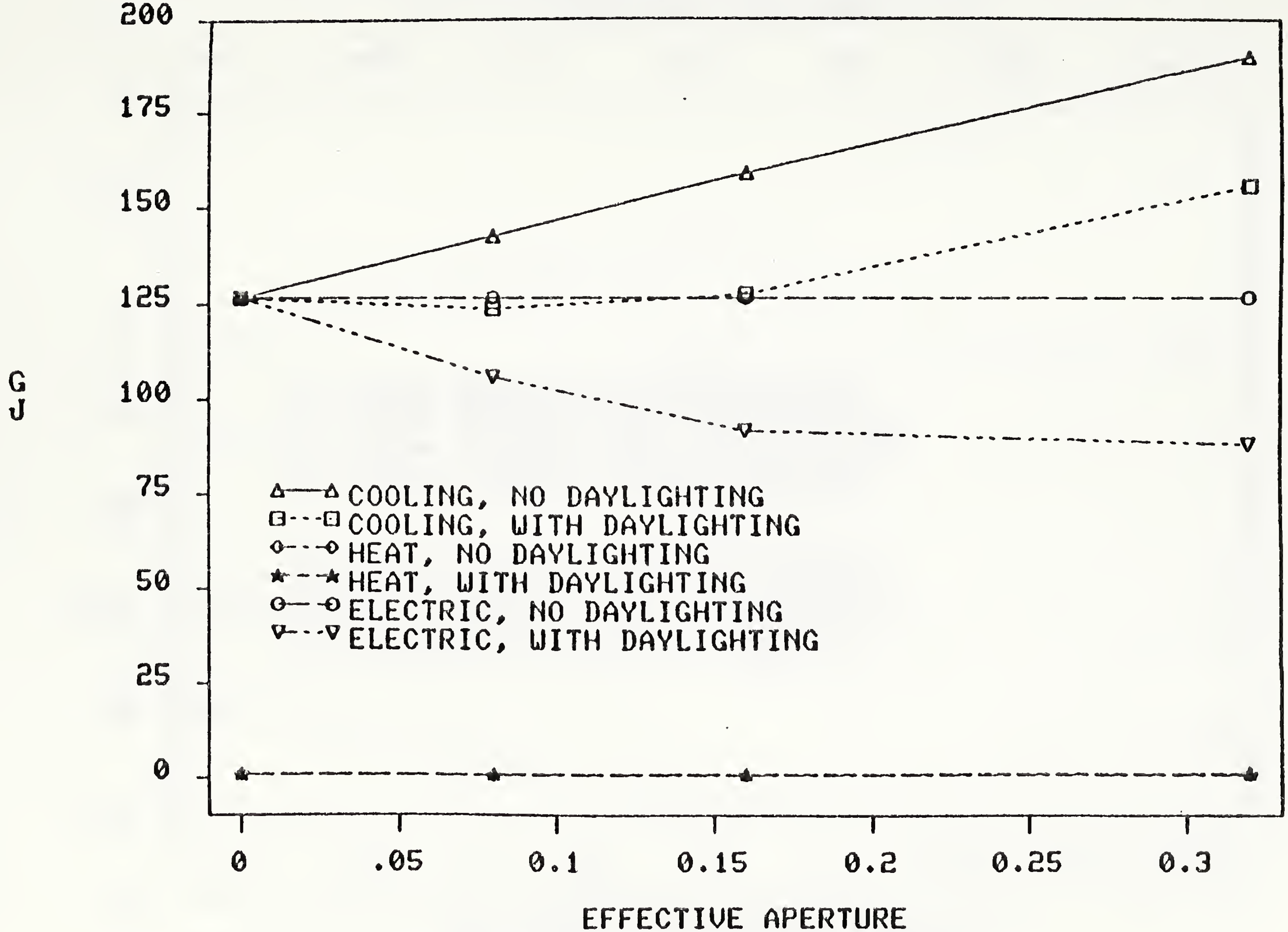


Figure 79. PEAK HEATING AND COOLING LOADS (Miami) SKYLIGHTS, BRICK FREESTANDING

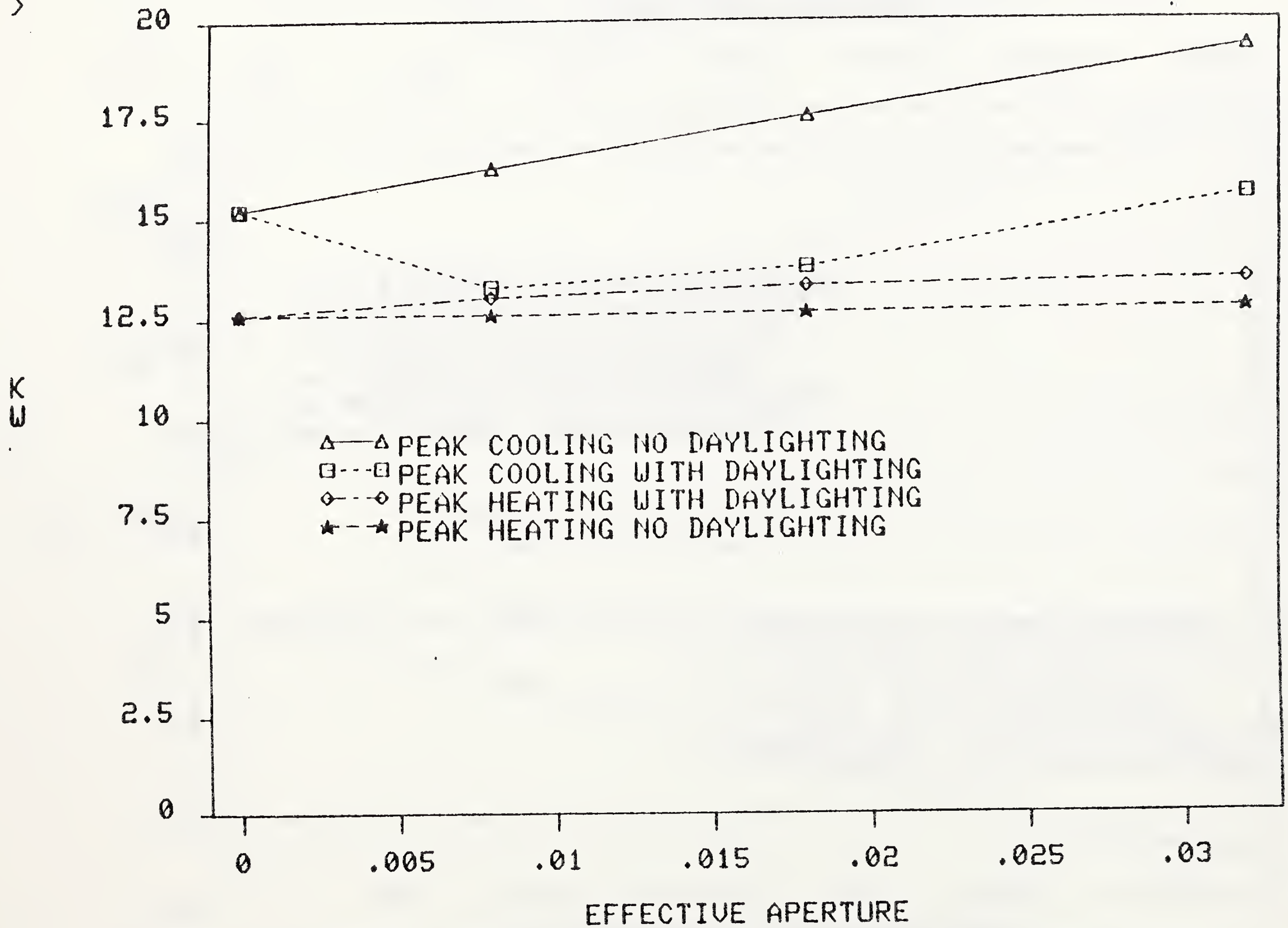


Figure 80. PEAK HEATING AND COOLING LOADS (Miami)
SOUTH SAWTOOTH, BRICK FREESTANDING

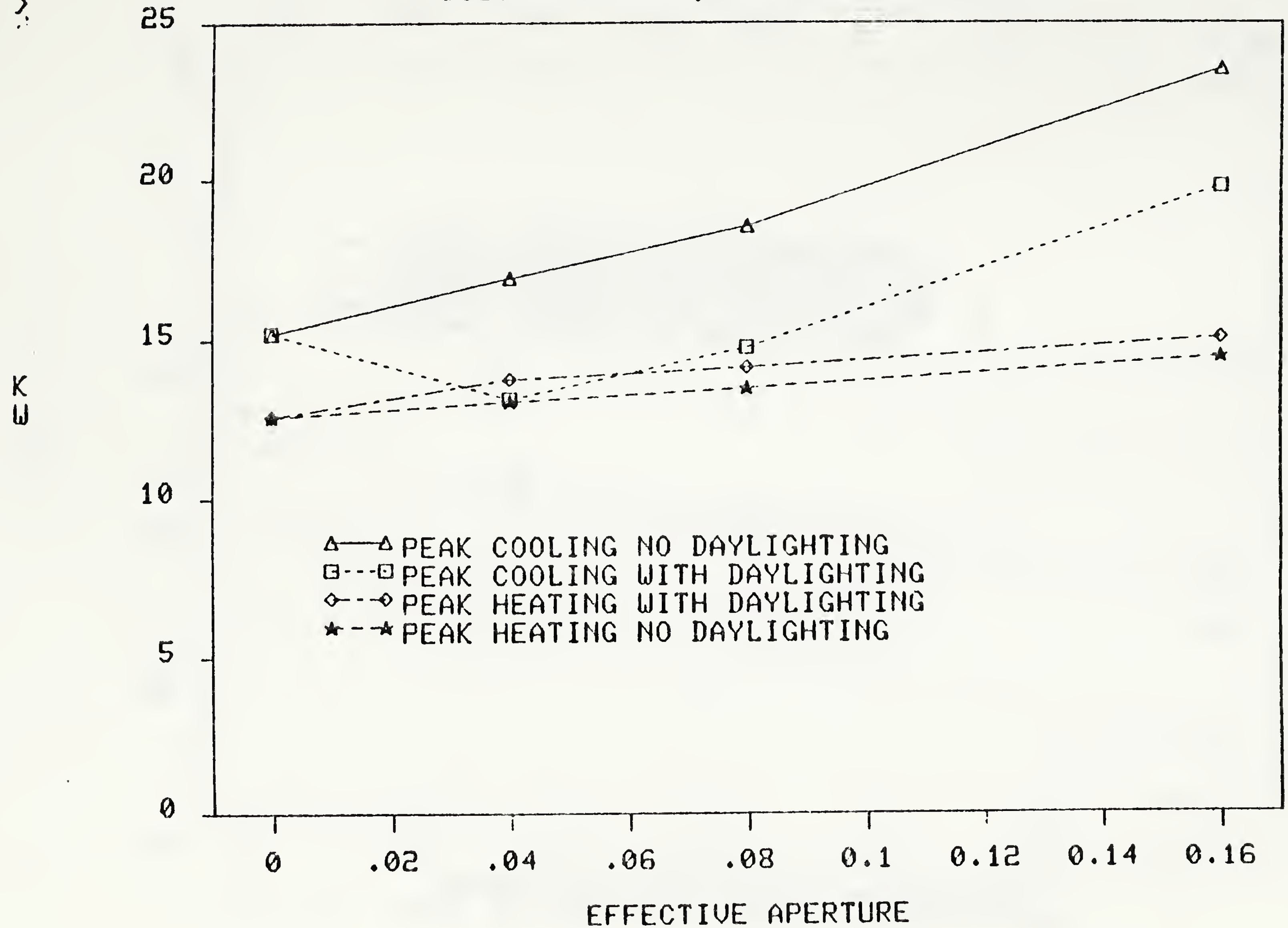


Figure 81. PEAK HEATING AND COOLING LOADS (Miami)
NORTH SAWTOOTH, BRICK FREESTANDING

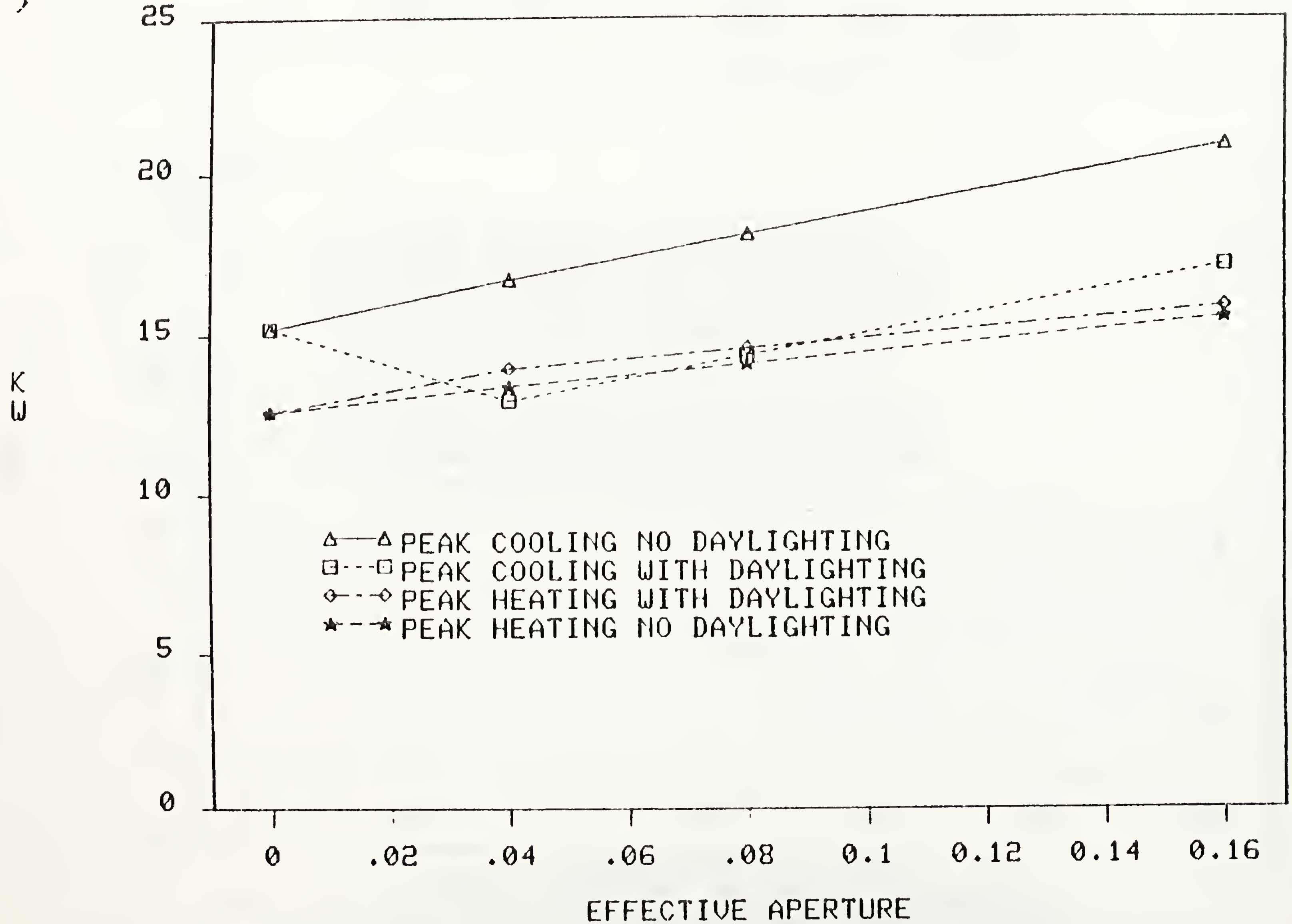


Figure 82. PEAK HEATING AND COOLING LOADS (Miami)
SOUTH WINDOW, BRICK FREESTANDING

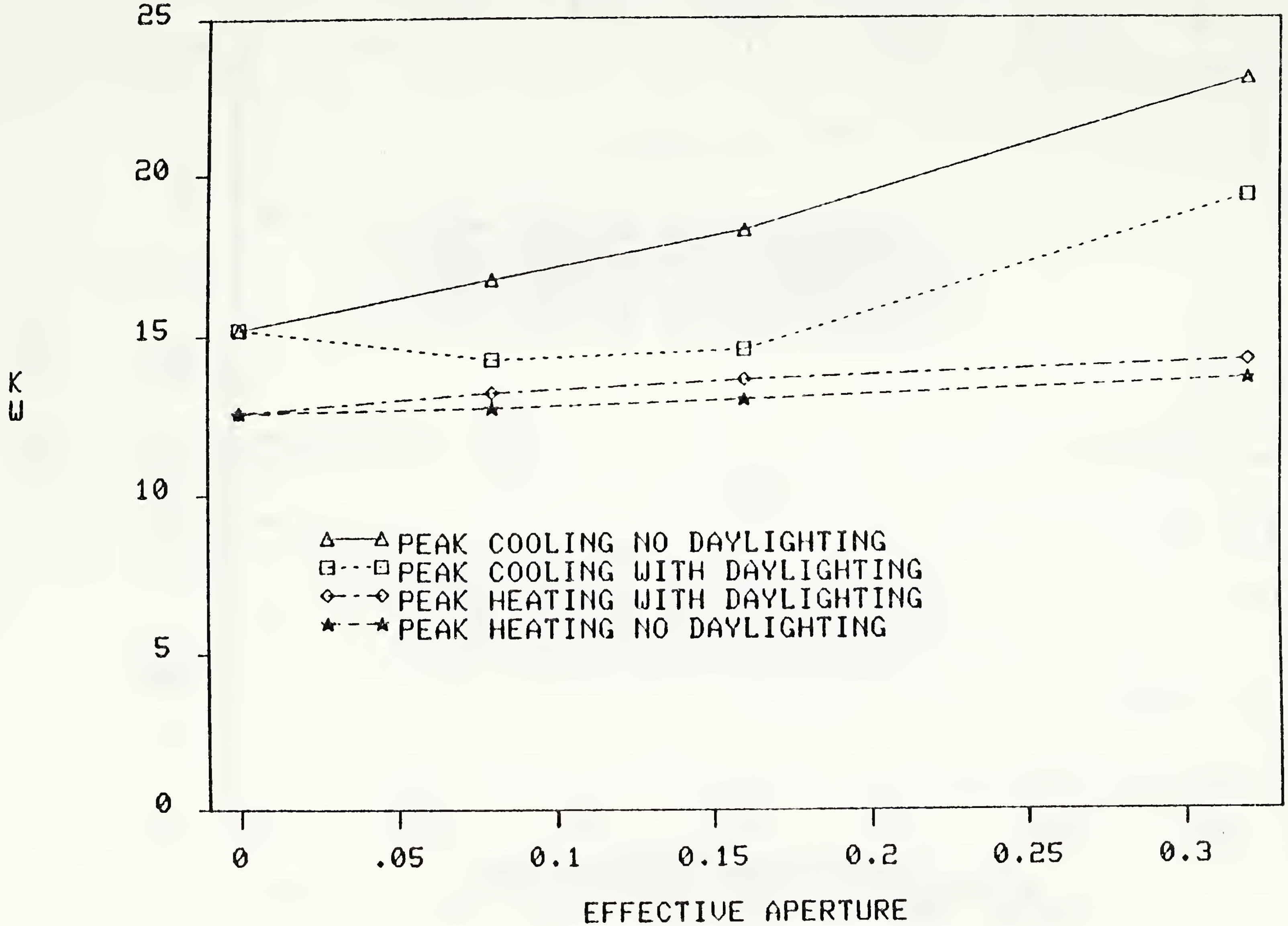


Figure 83. PEAK HEATING AND COOLING LOADS (Miami)
NORTH WINDOW, BRICK FREESTANDING

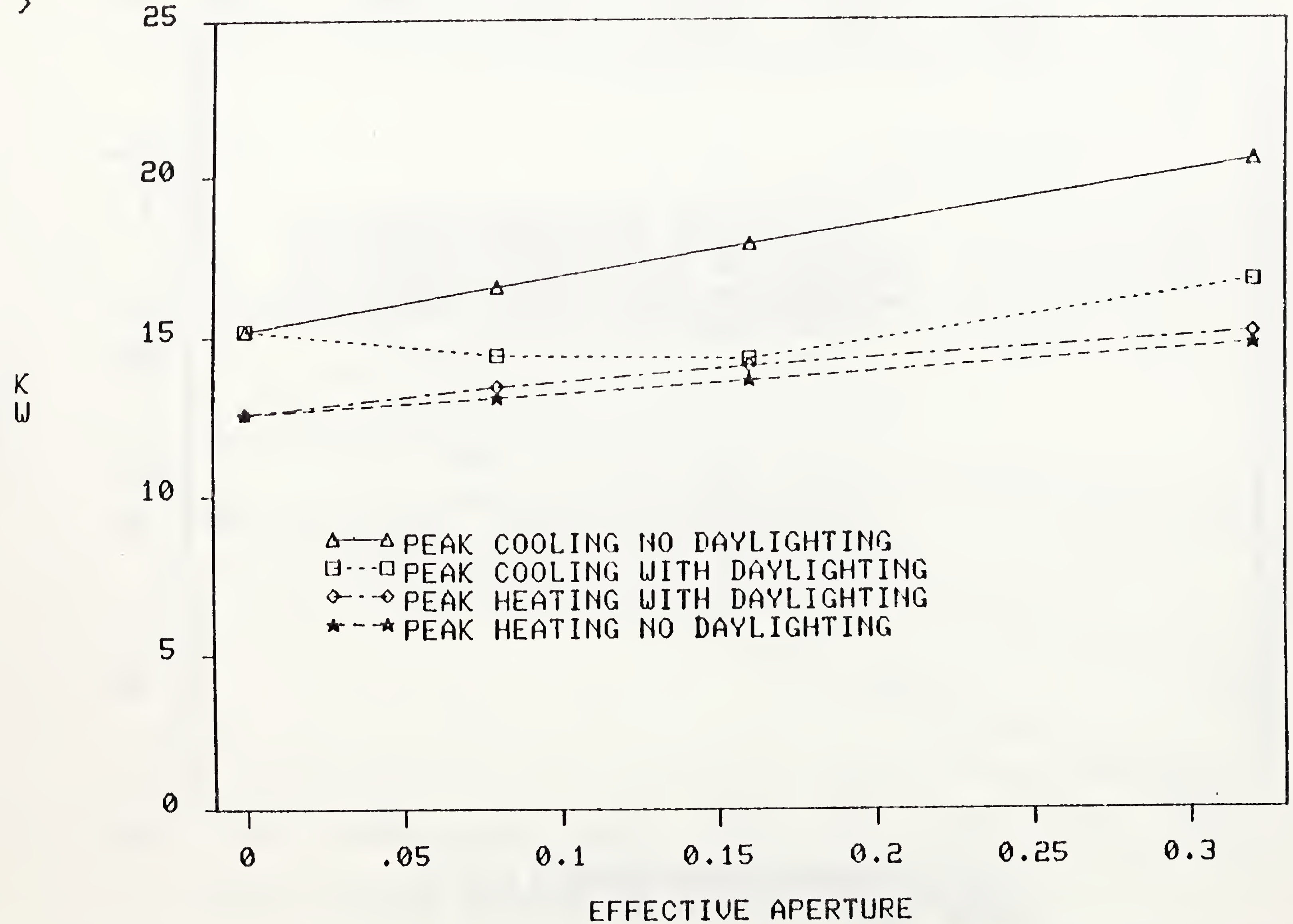


Figure 84. PEAK HEATING AND COOLING LOADS (Miami)
SKYLIGHTS, BRICK ATTACHED

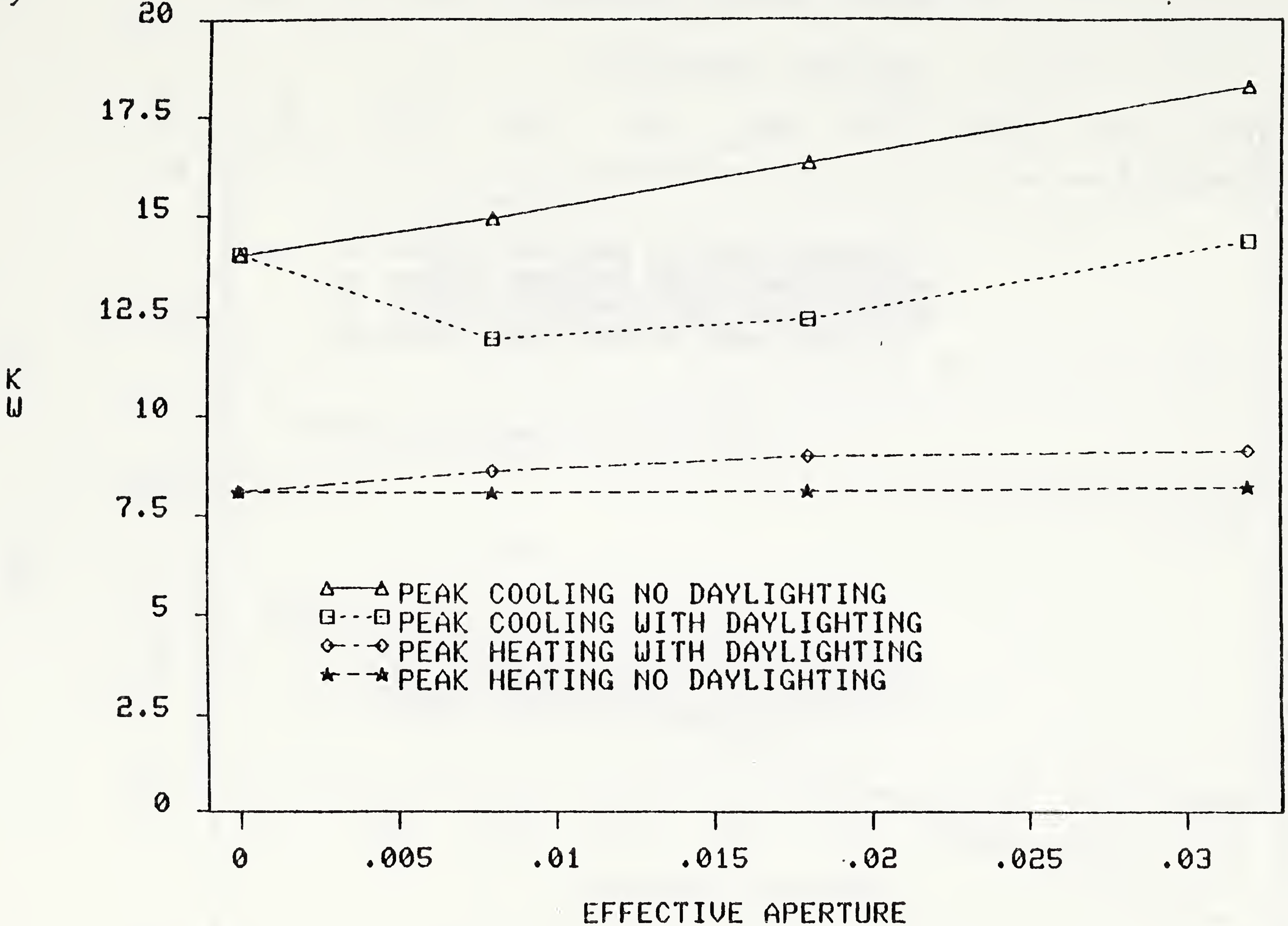


Figure 85. PEAK HEATING AND COOLING LOADS (Miami)
SOUTH SAWTOOTH, BRICK ATTACHED

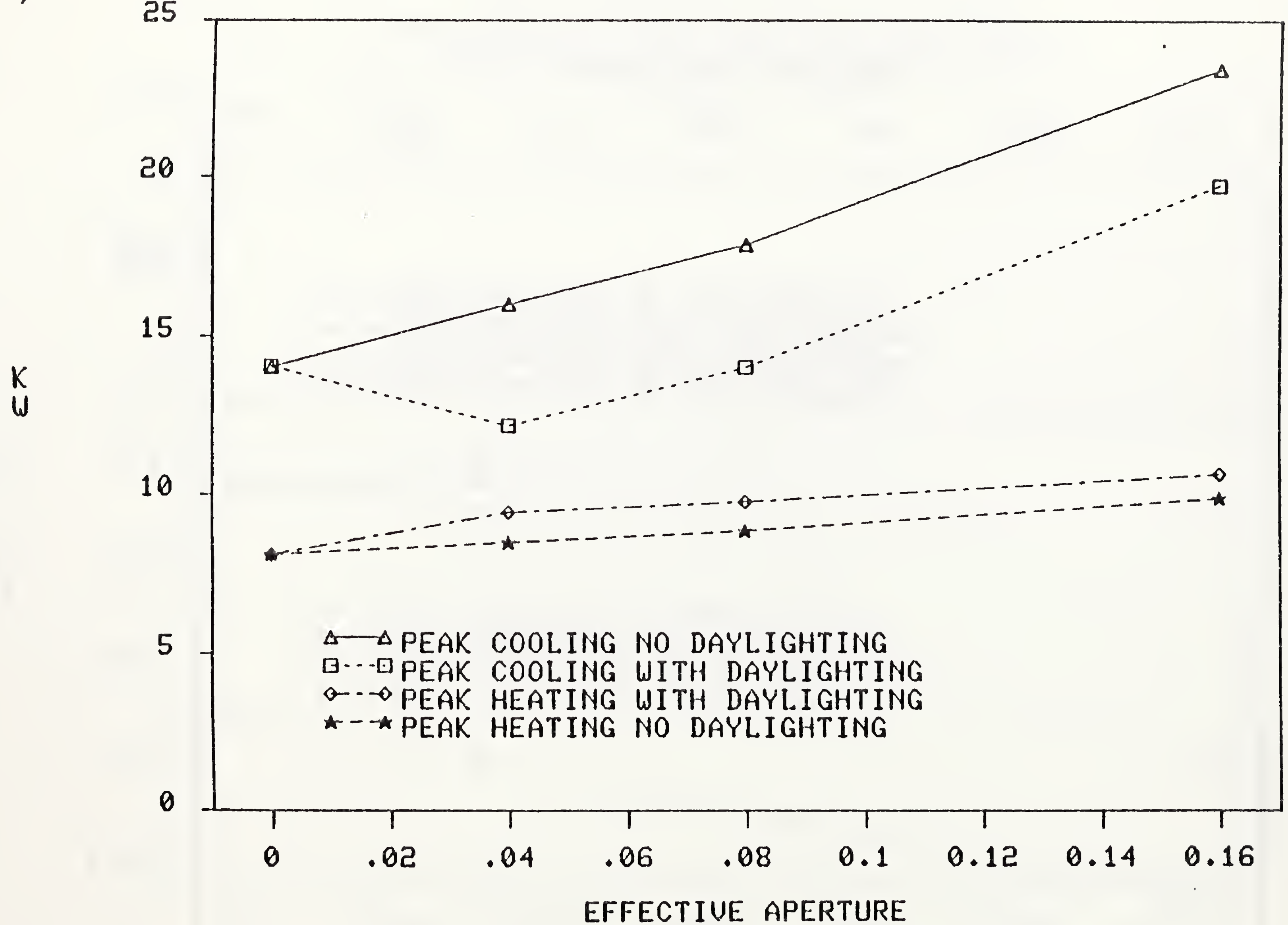


Figure 86. PEAK HEATING AND COOLING LOADS (Miami)
NORTH SAWTOOTH, BRICK ATTACHED

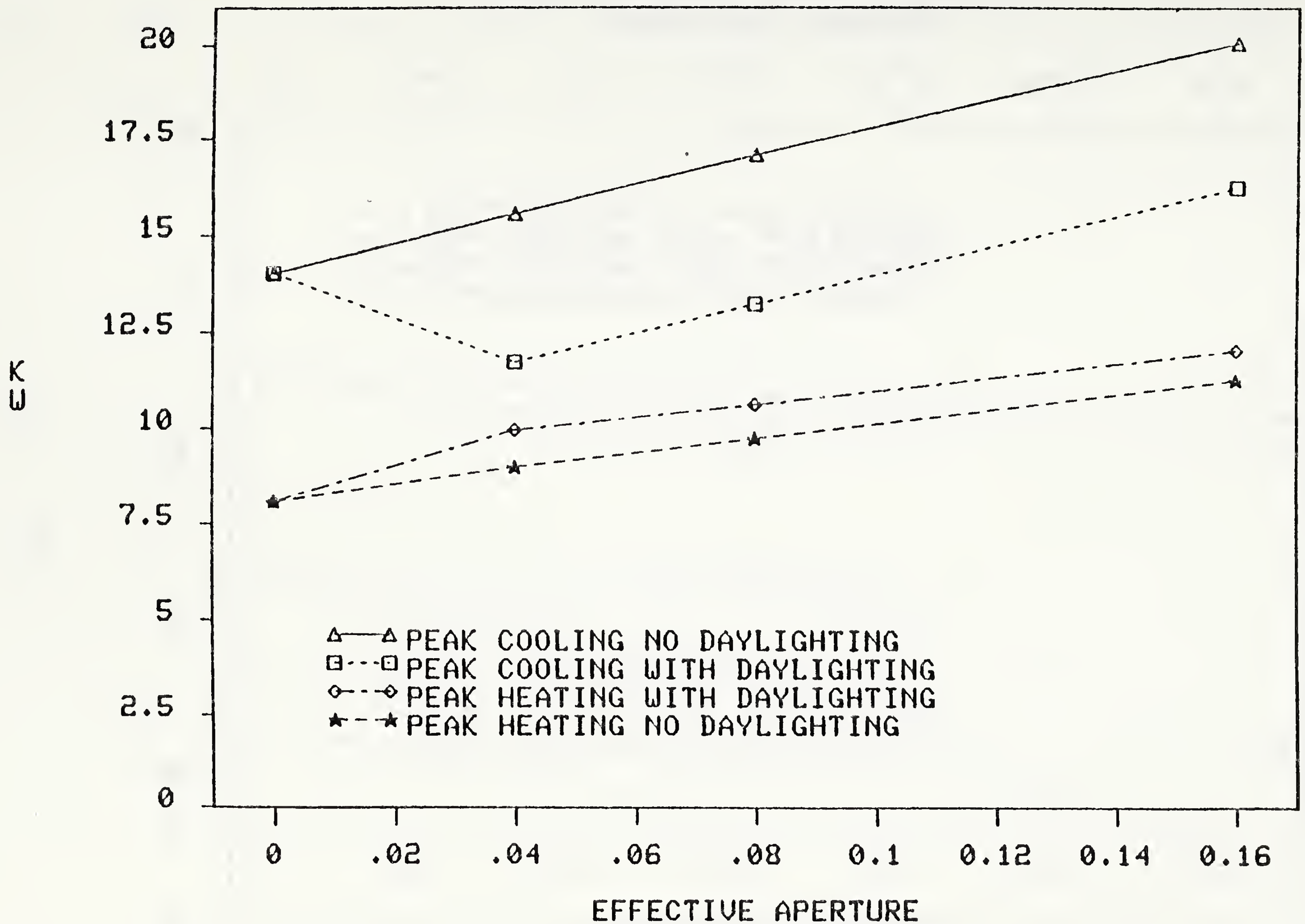


Figure 87. PEAK HEATING AND COOLING LOADS (Miami) SOUTH WINDOW, BRICK ATTACHED

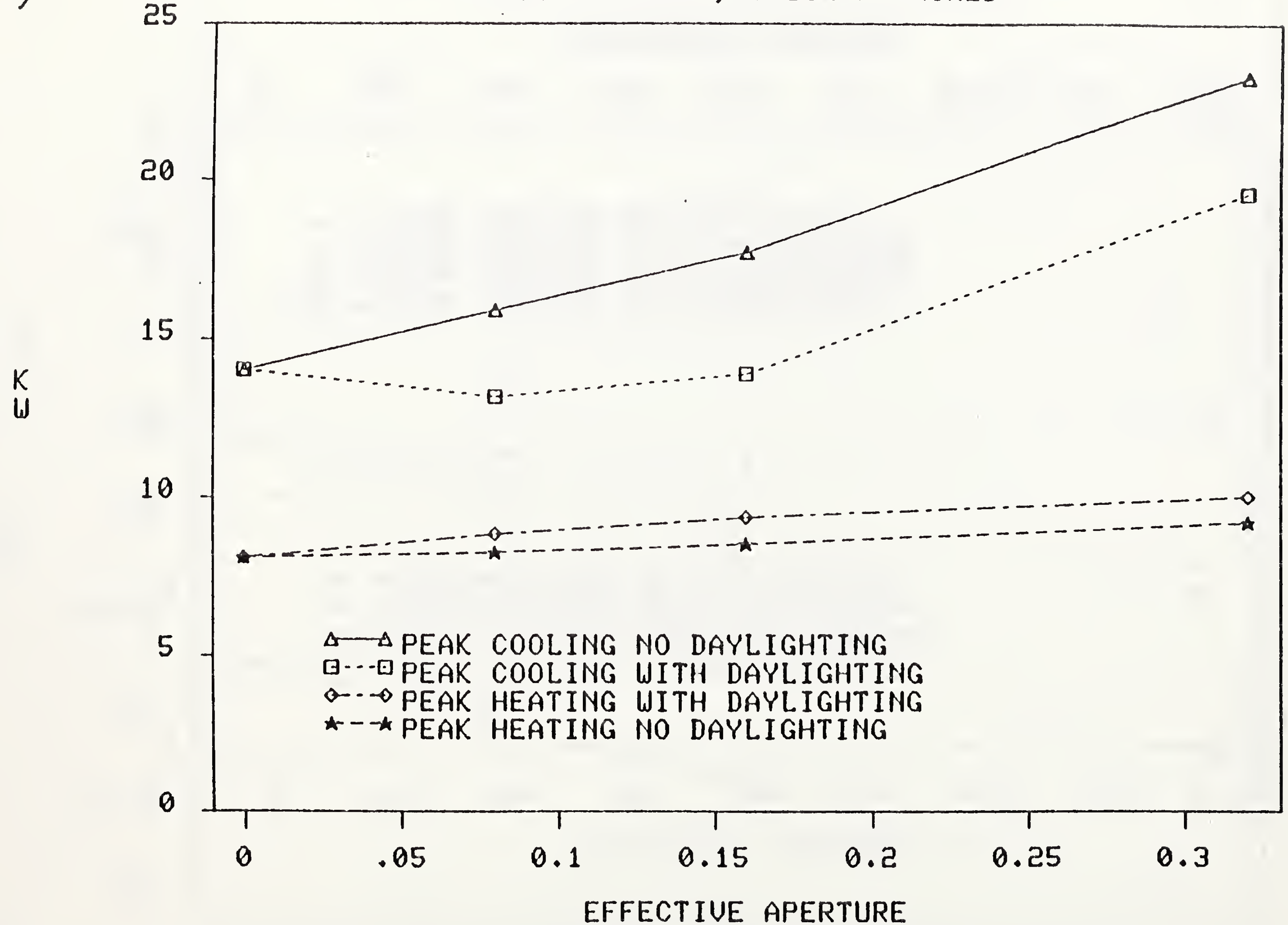


Figure 88. PEAK HEATING AND COOLING LOADS (Miami)
NORTH WINDOW, BRICK ATTACHED

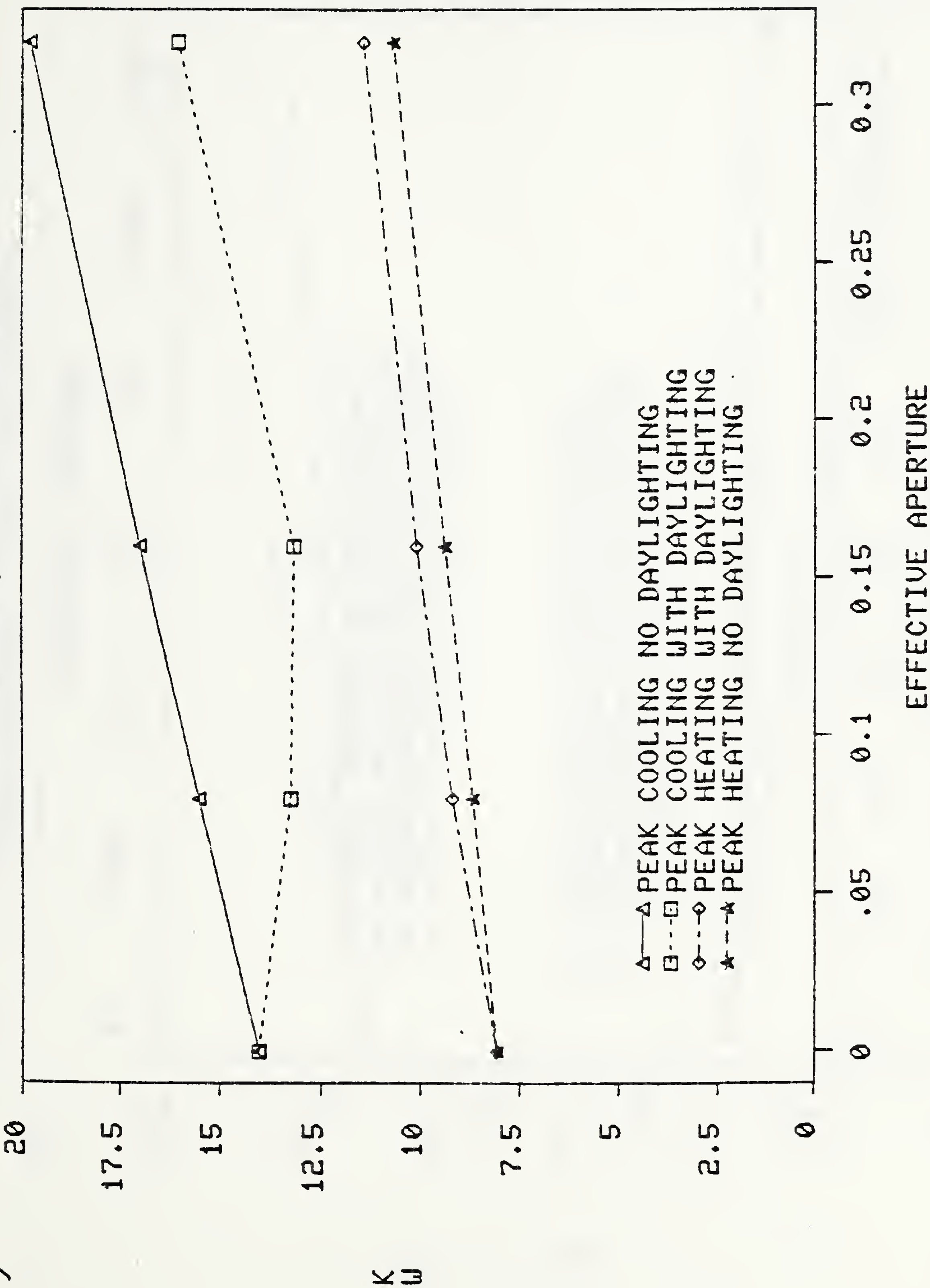


Figure 89. PEAK HEATING AND COOLING LOADS (Miami)
SKYLIGHTS, METAL FREESTANDING

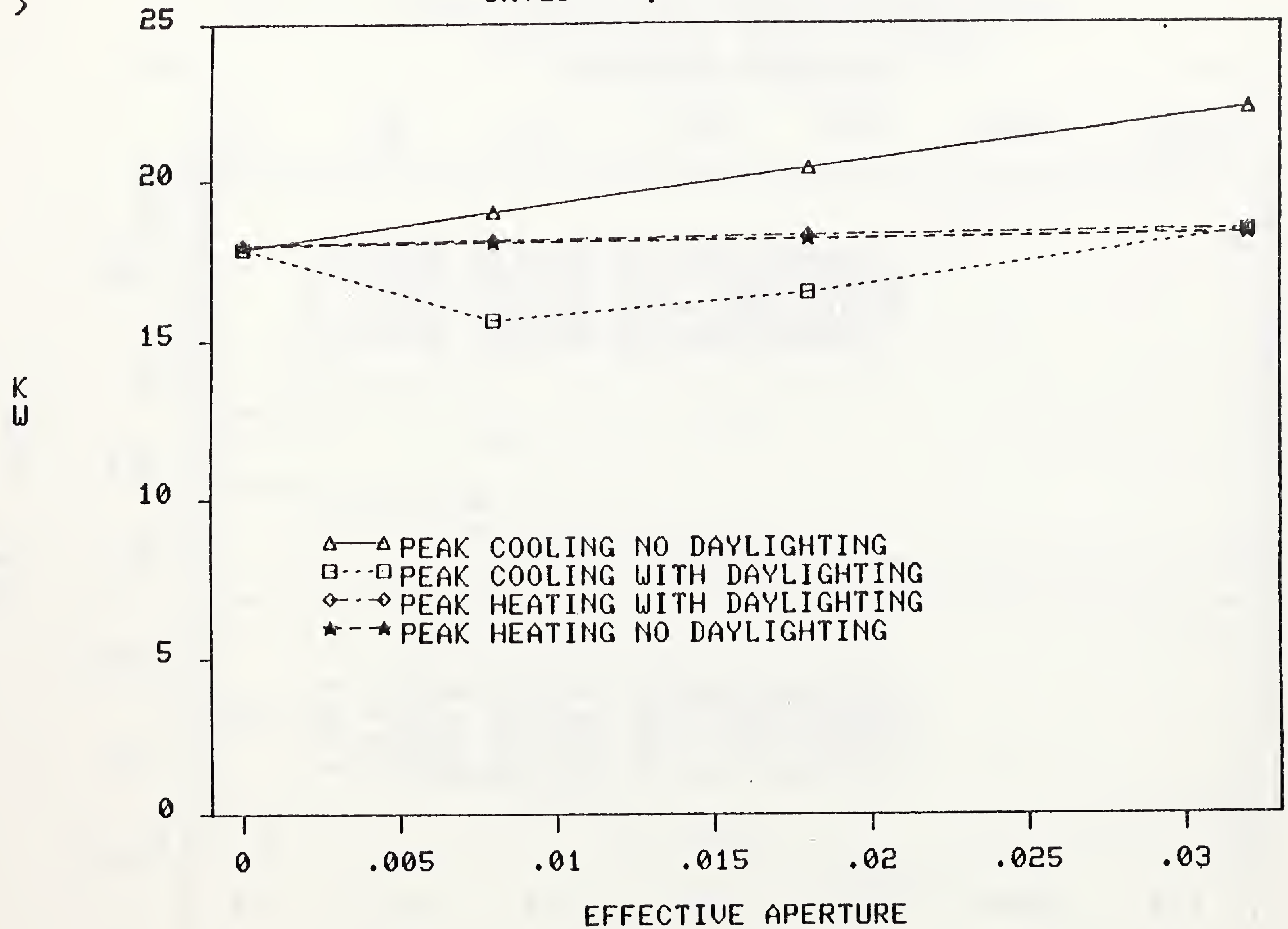


Figure 90. PEAK HEATING AND COOLING LOADS (Miami)
SOUTH SAWTOOTH, METAL FREESTANDING

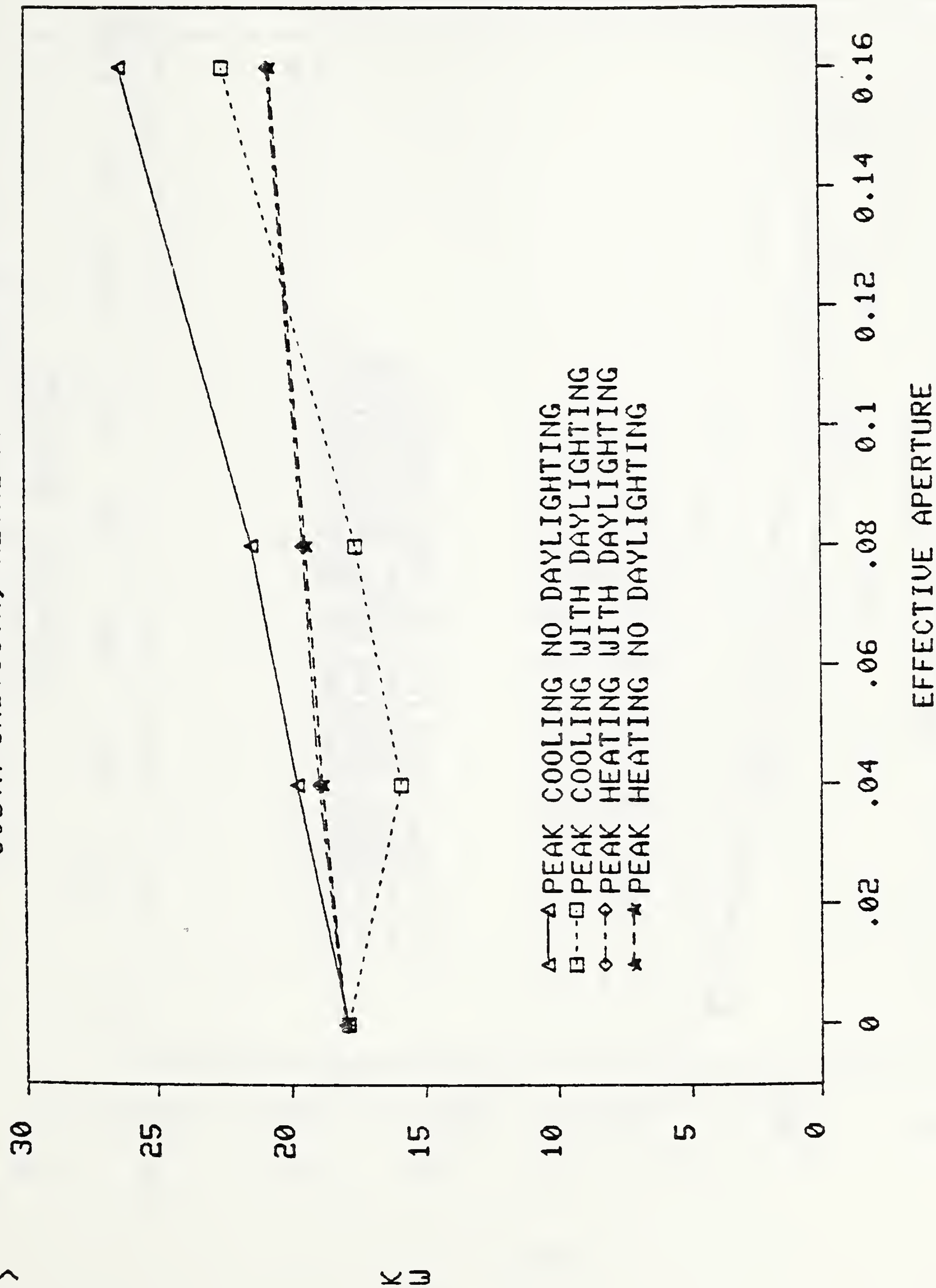


Figure 91. PEAK HEATING AND COOLING LOADS (Miami)
NORTH SAWTOOTH, METAL FREESTANDING

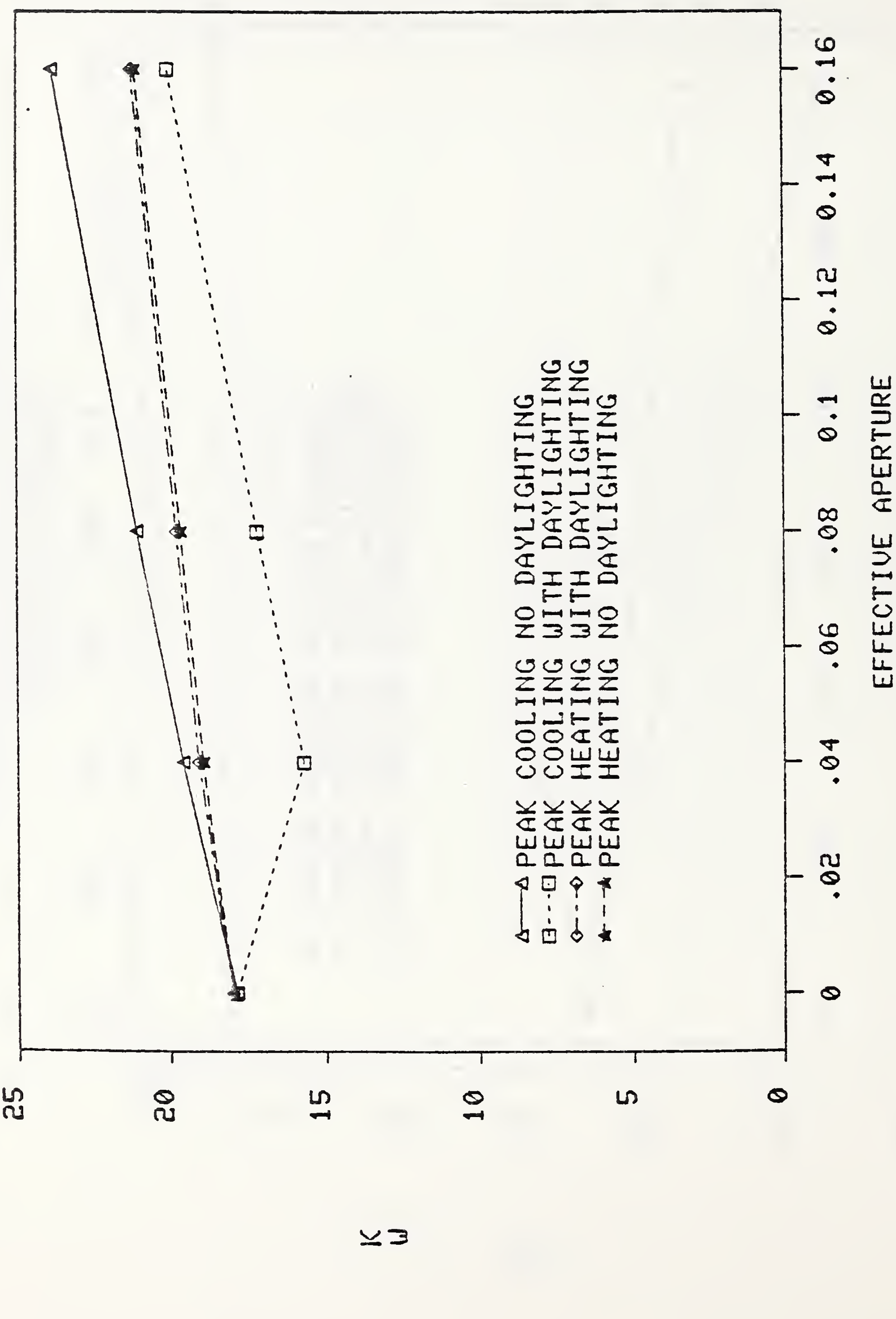


Figure 92. PEAK HEATING AND COOLING LOADS (Miami)
SOUTH WINDOW, METAL FREESTANDING

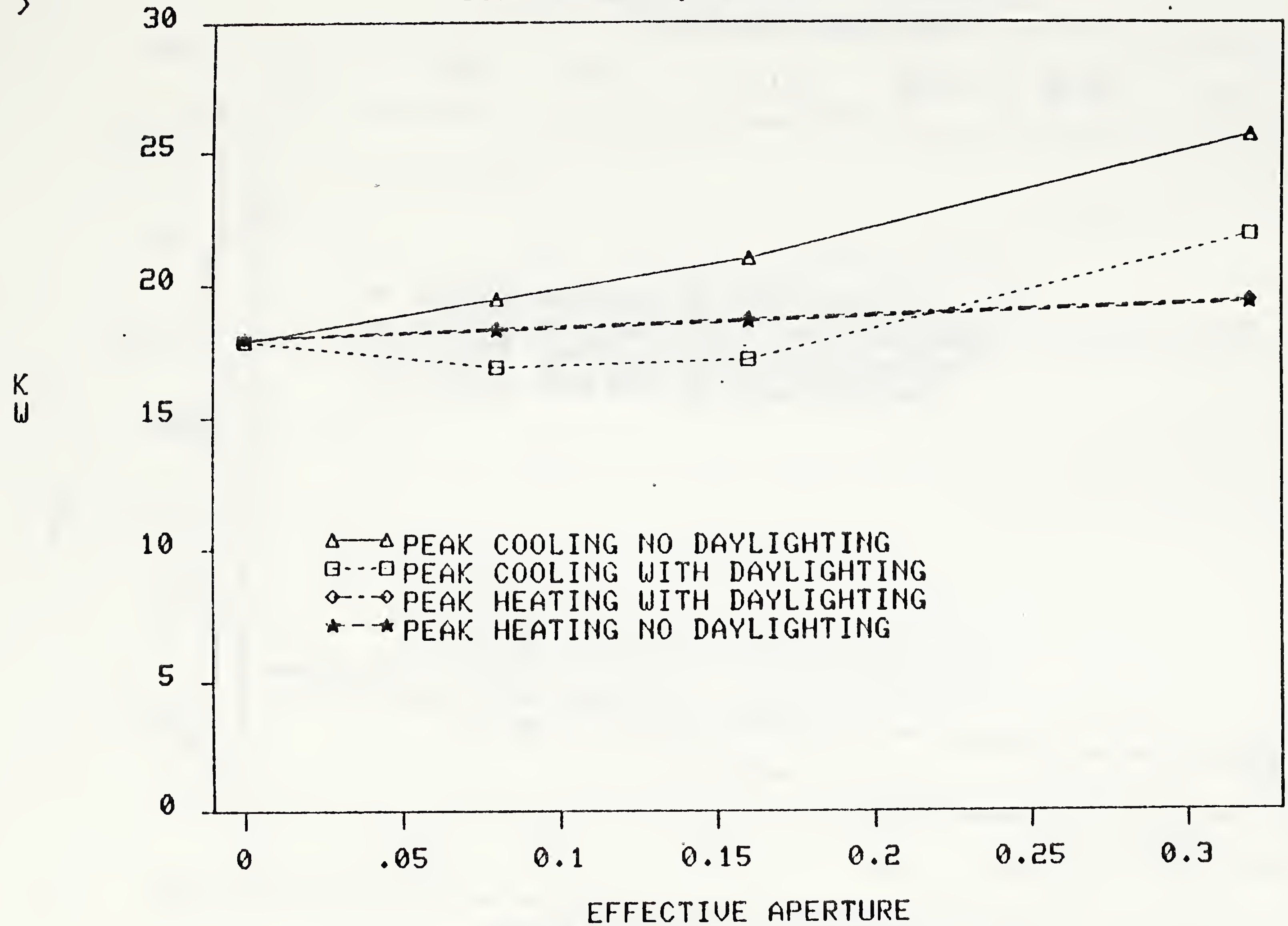


Figure 93. PEAK HEATING AND COOLING LOADS (Miami)
NORTH WINDOW, METAL FREESTANDING

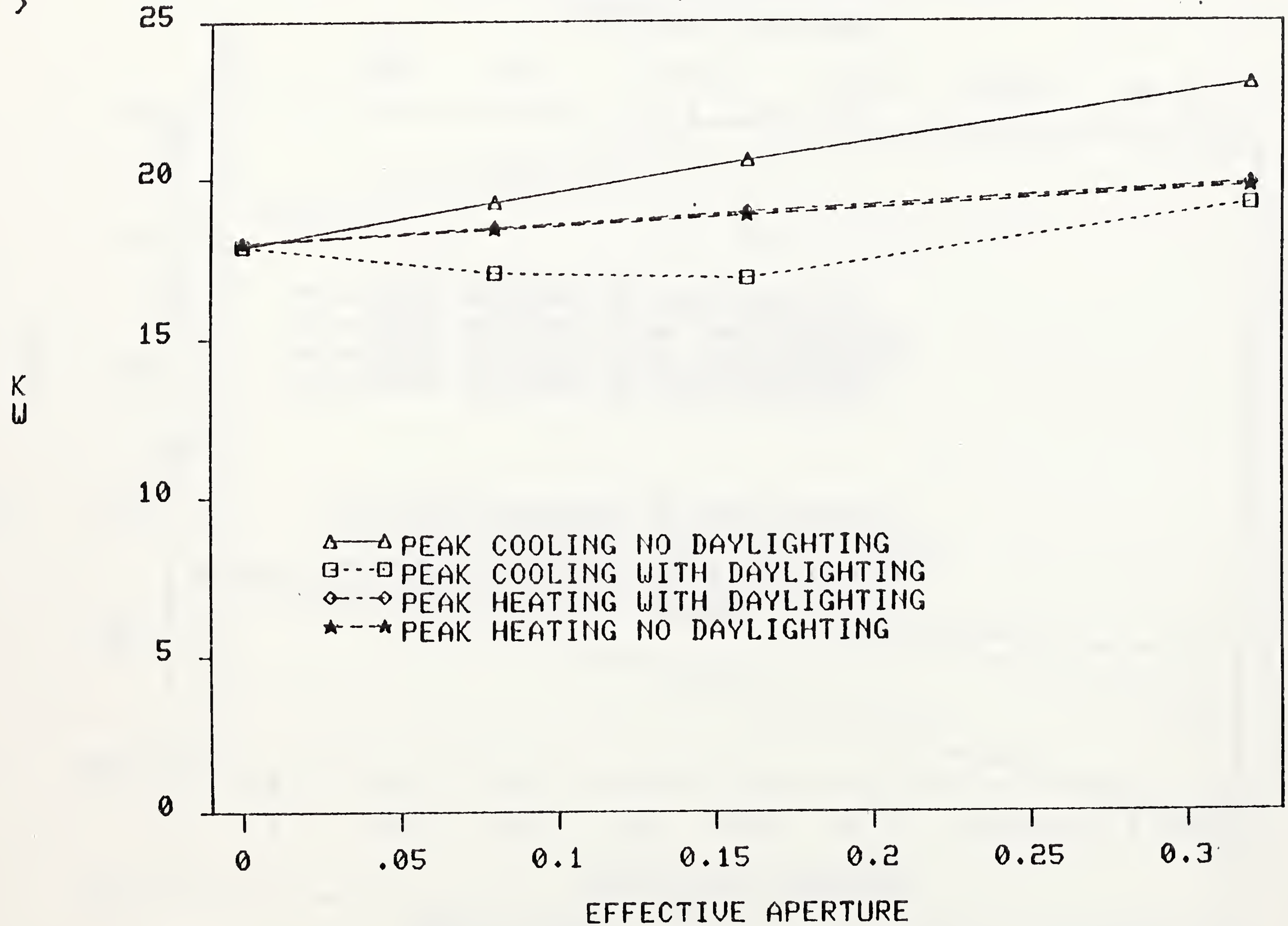


Figure 94. PEAK HEATING AND COOLING LOADS (Miami)
SKYLIGHTS, METAL ATTACHED

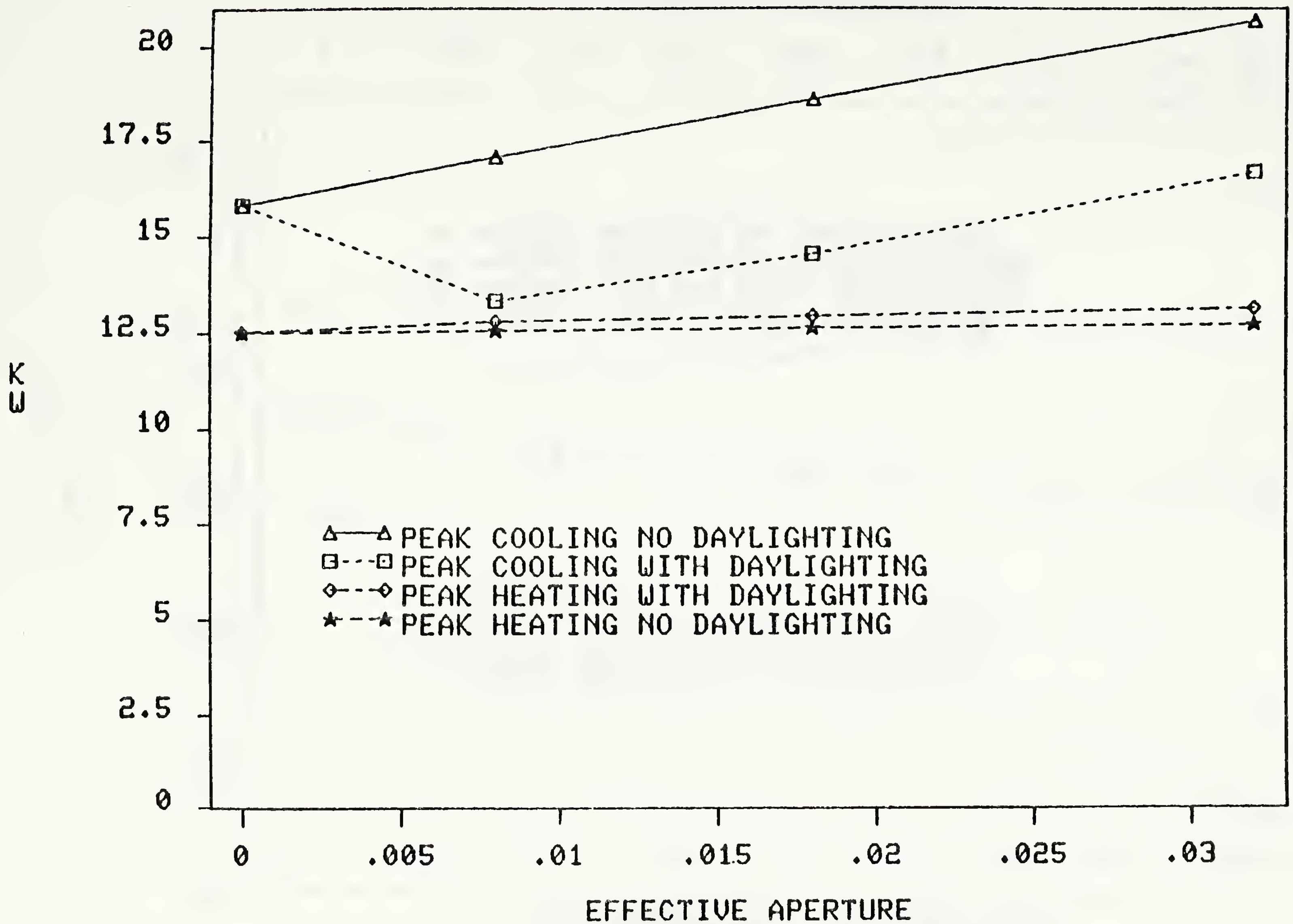


Figure 95. PEAK HEATING AND COOLING LOADS (Miami) SOUTH SAWTOOTH, METAL ATTACHED

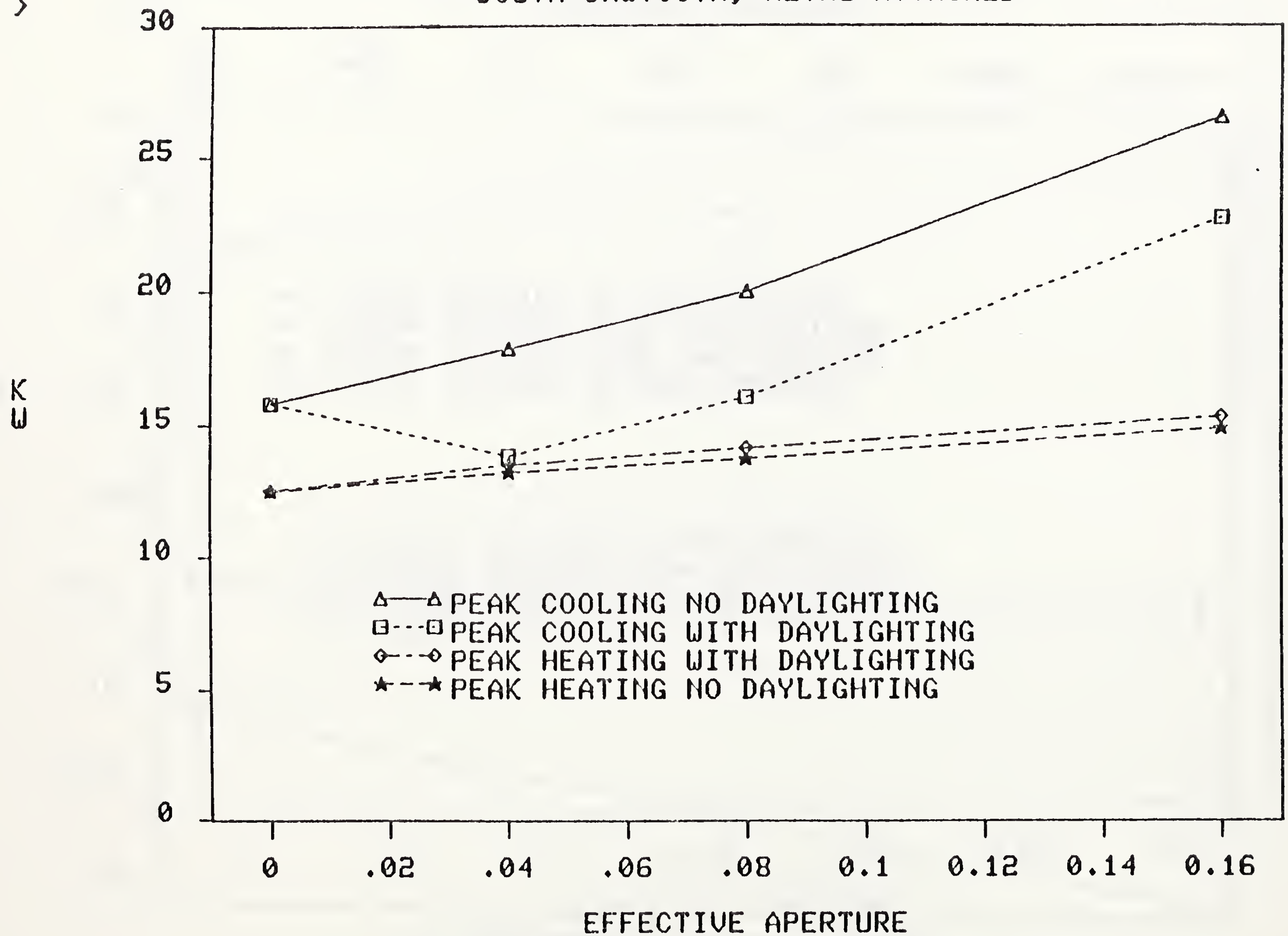


Figure 96. PEAK HEATING AND COOLING LOADS (Miami)
NORTH SAWTOOTH, METAL ATTACHED

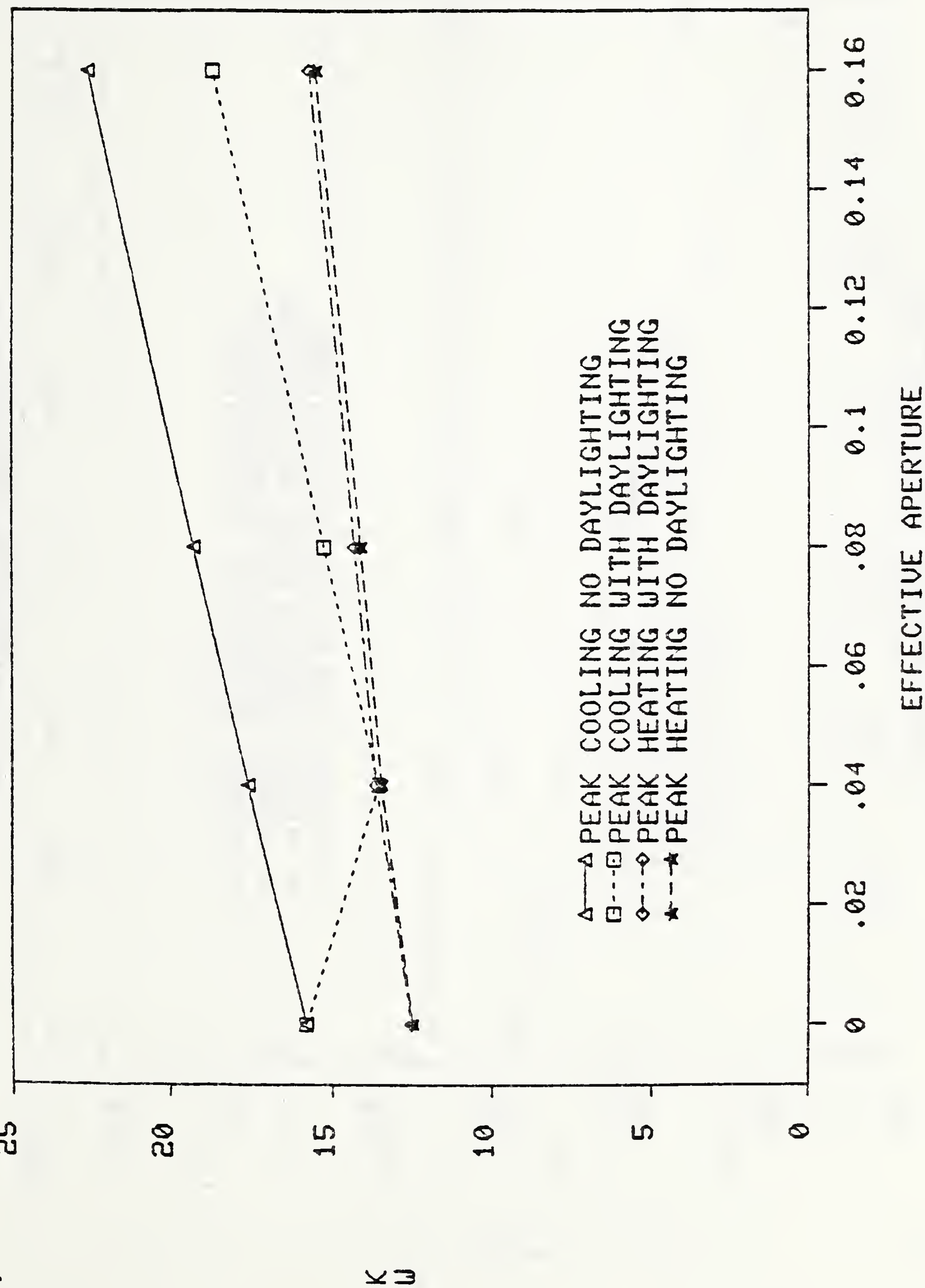


Figure 97. PEAK HEATING AND COOLING LOADS (Miami)
SOUTH WINDOW, METAL ATTACHED

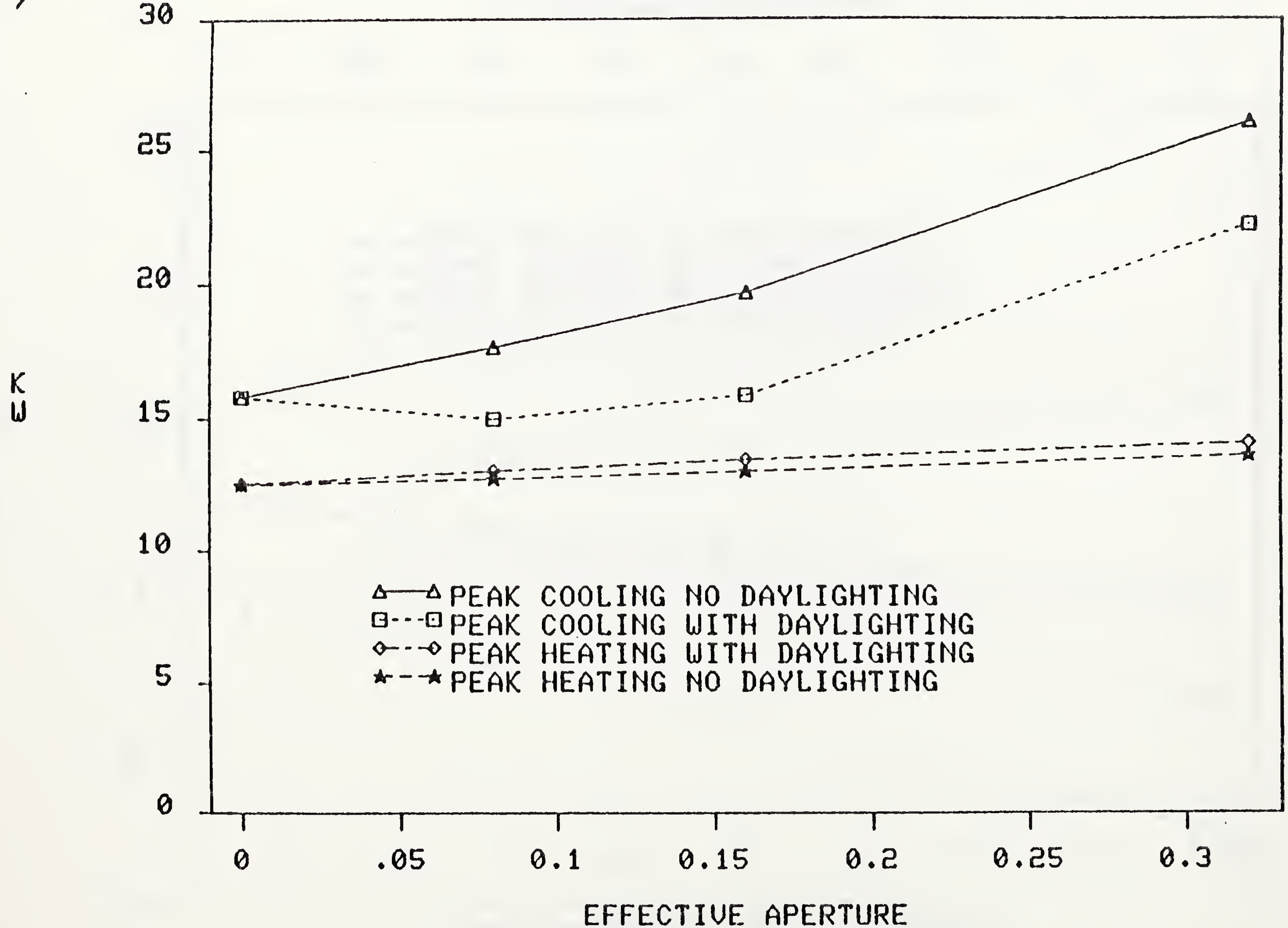


Figure 98. PEAK HEATING AND COOLING LOADS (Miami)
NORTH WINDOW, METAL ATTACHED

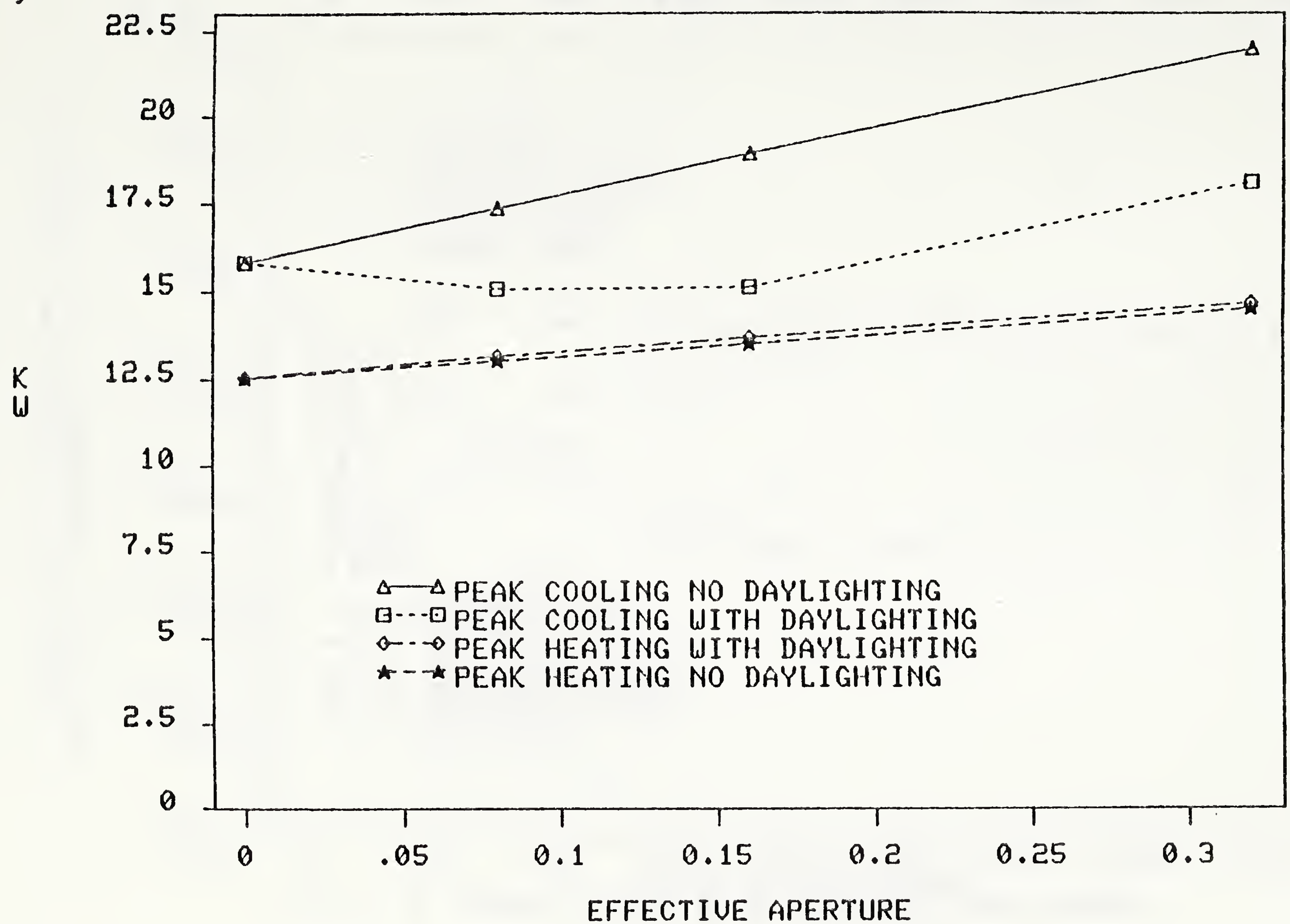


Figure 99. TOTAL ENERGY WITH DAYLIGHT (San Diego)
BRICK FREESTANDING

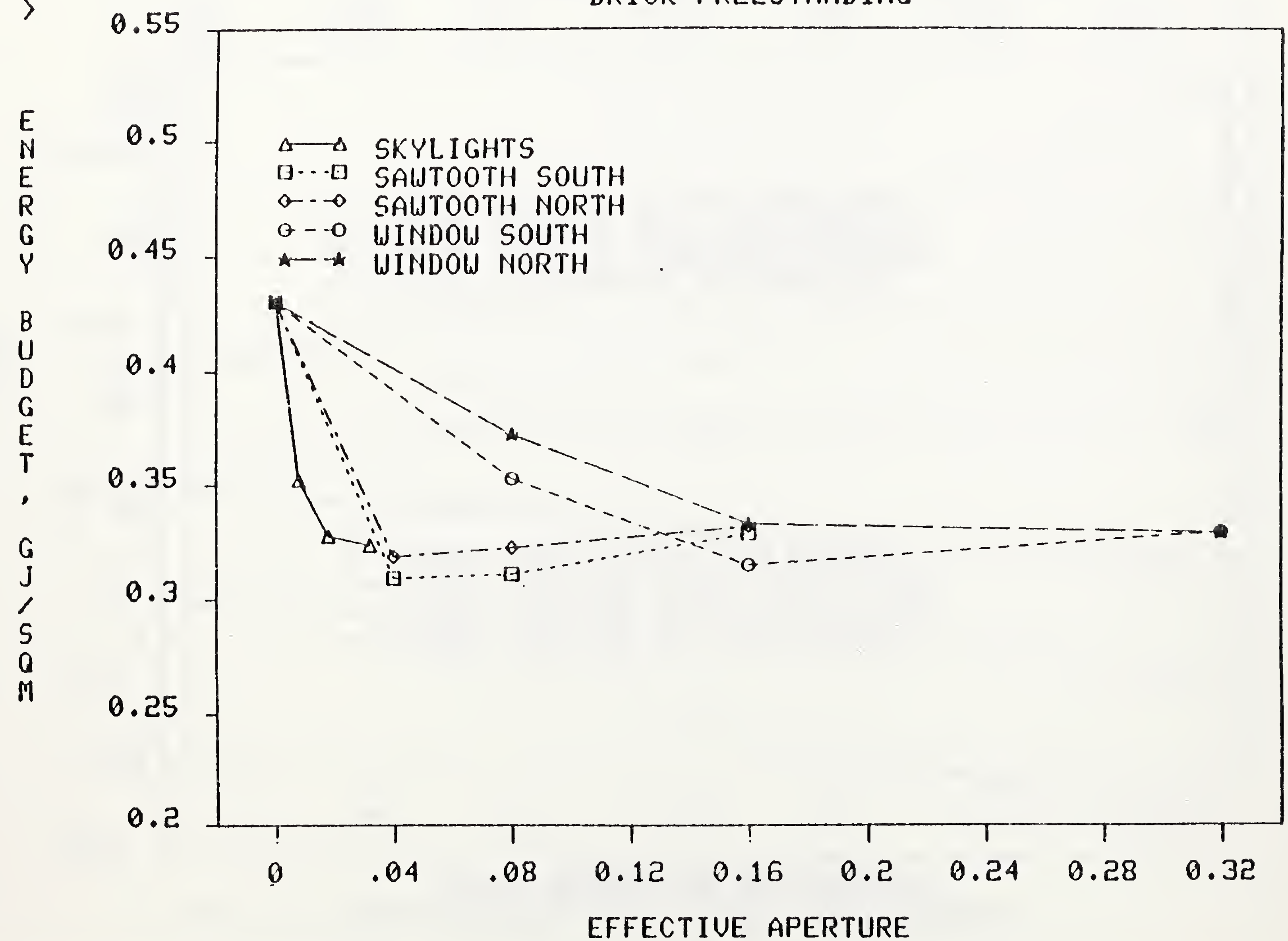


Figure 100. TOTAL ENERGY WITH DAYLIGHT (San Diego)
BRICK ATTACHED

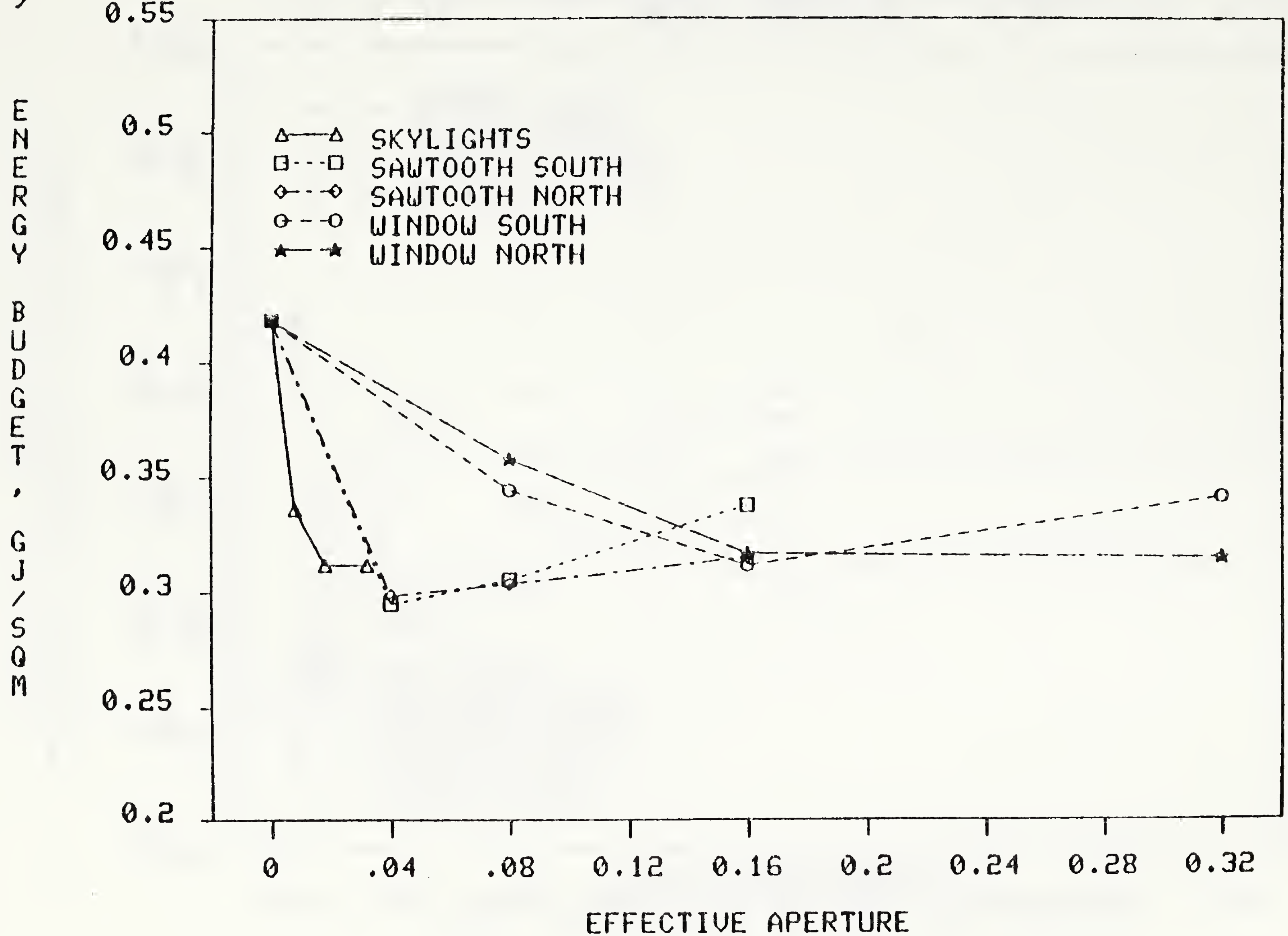


Figure 101. TOTAL ENERGY WITH DAYLIGHT (San Diego)
METAL FREESTANDING

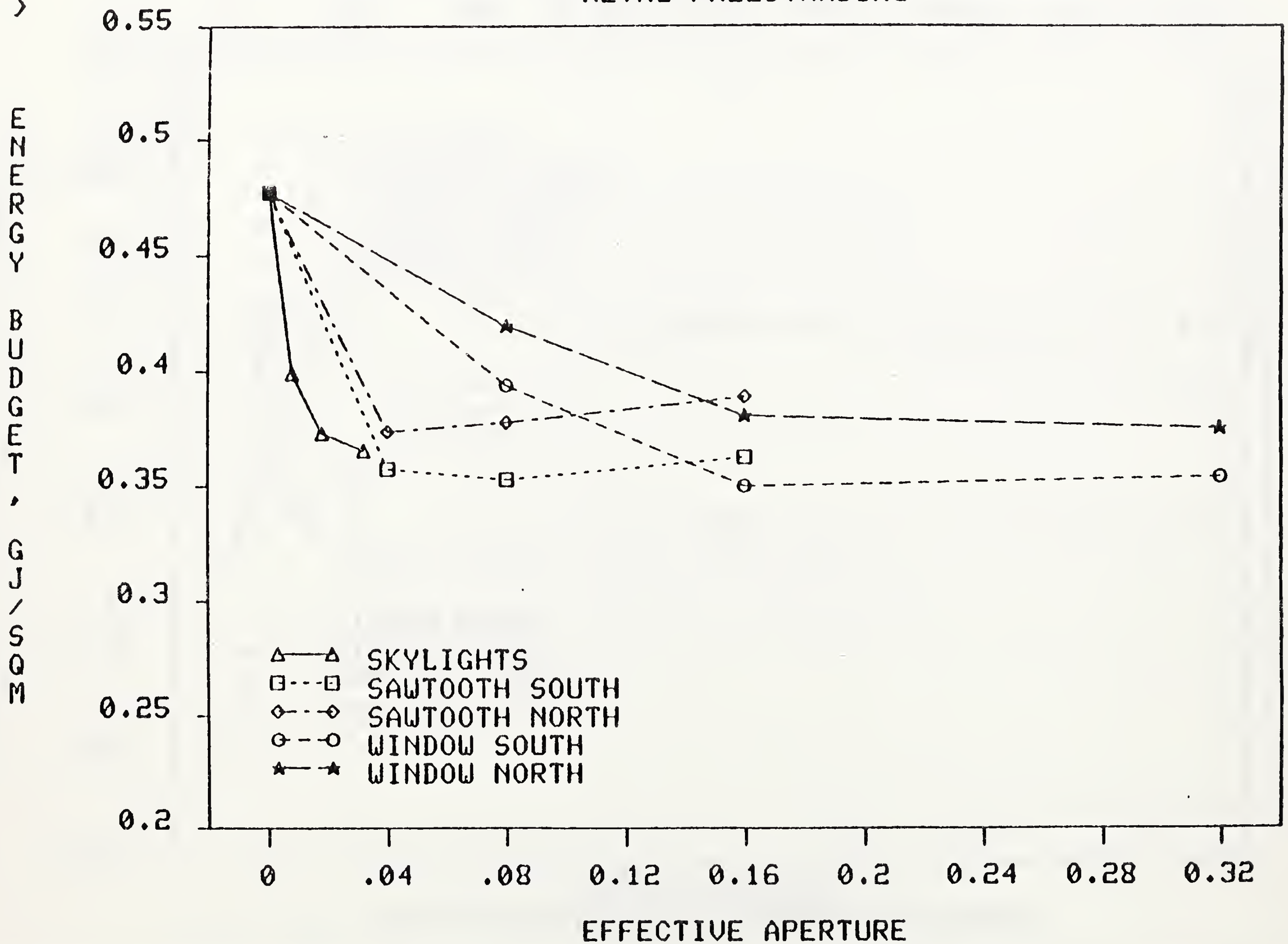


Figure 102. TOTAL ENERGY WITH DAYLIGHT (San Diego)
METAL ATTACHED

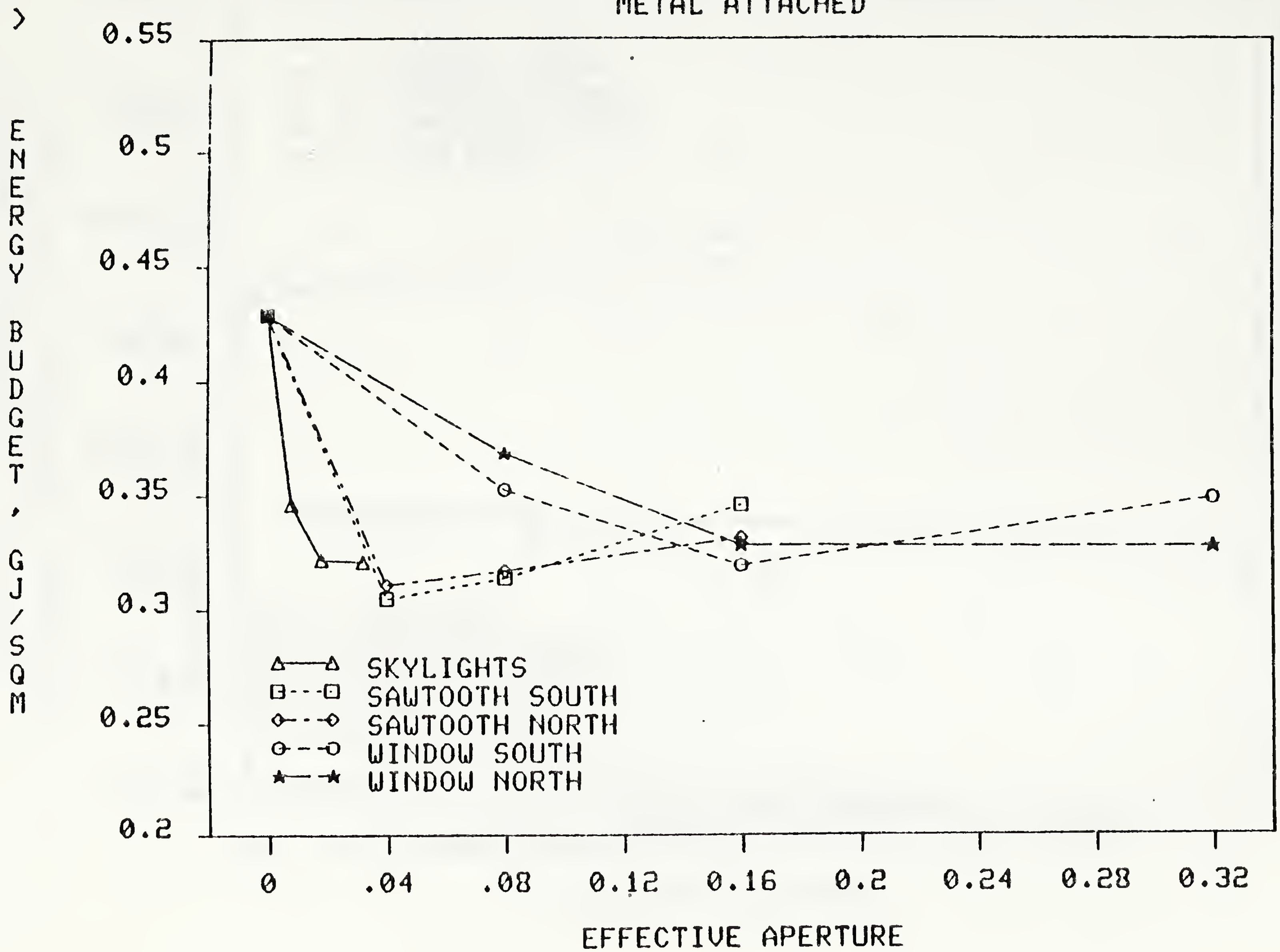


Figure 103. TOTAL ENERGY WITHOUT DAYLIGHT (San Diego)
BRICK FREESTANDING

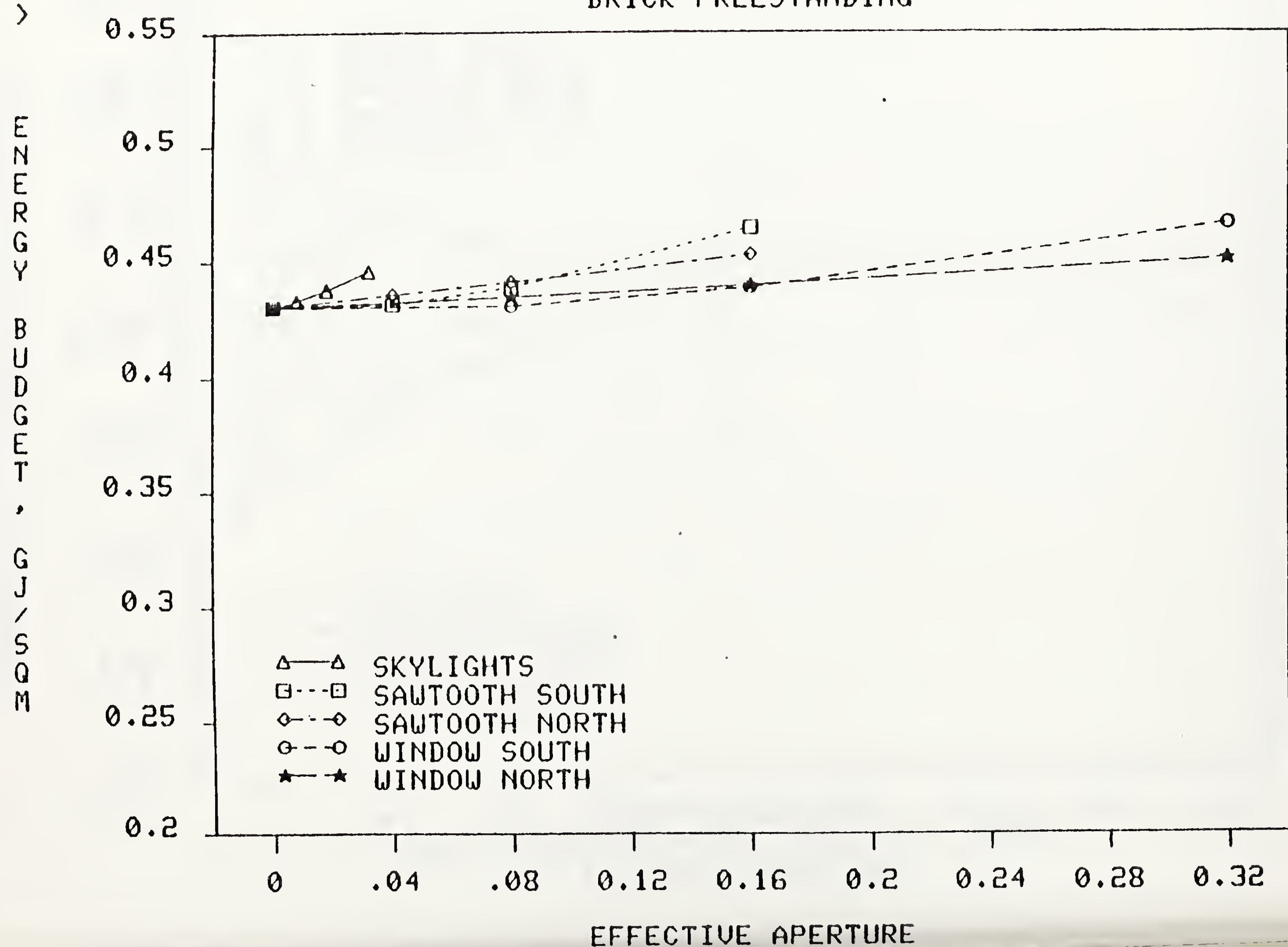


Figure 104. TOTAL ENERGY WITHOUT DAYLIGHT (San Diego)
BRICK ATTACHED

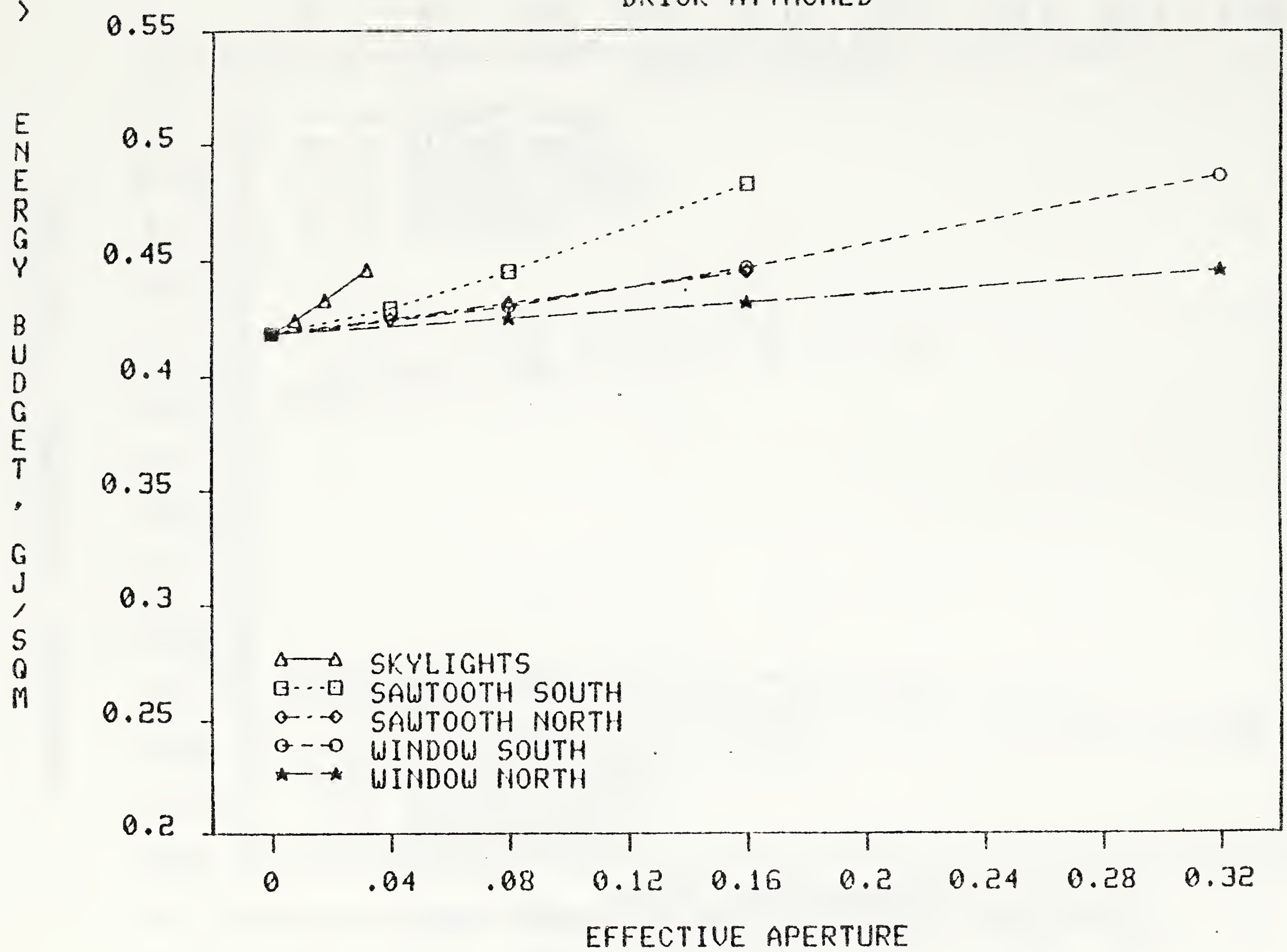


Figure 105. TOTAL ENERGY WITHOUT DAYLIGHT (San Diego)
METAL FREESTANDING

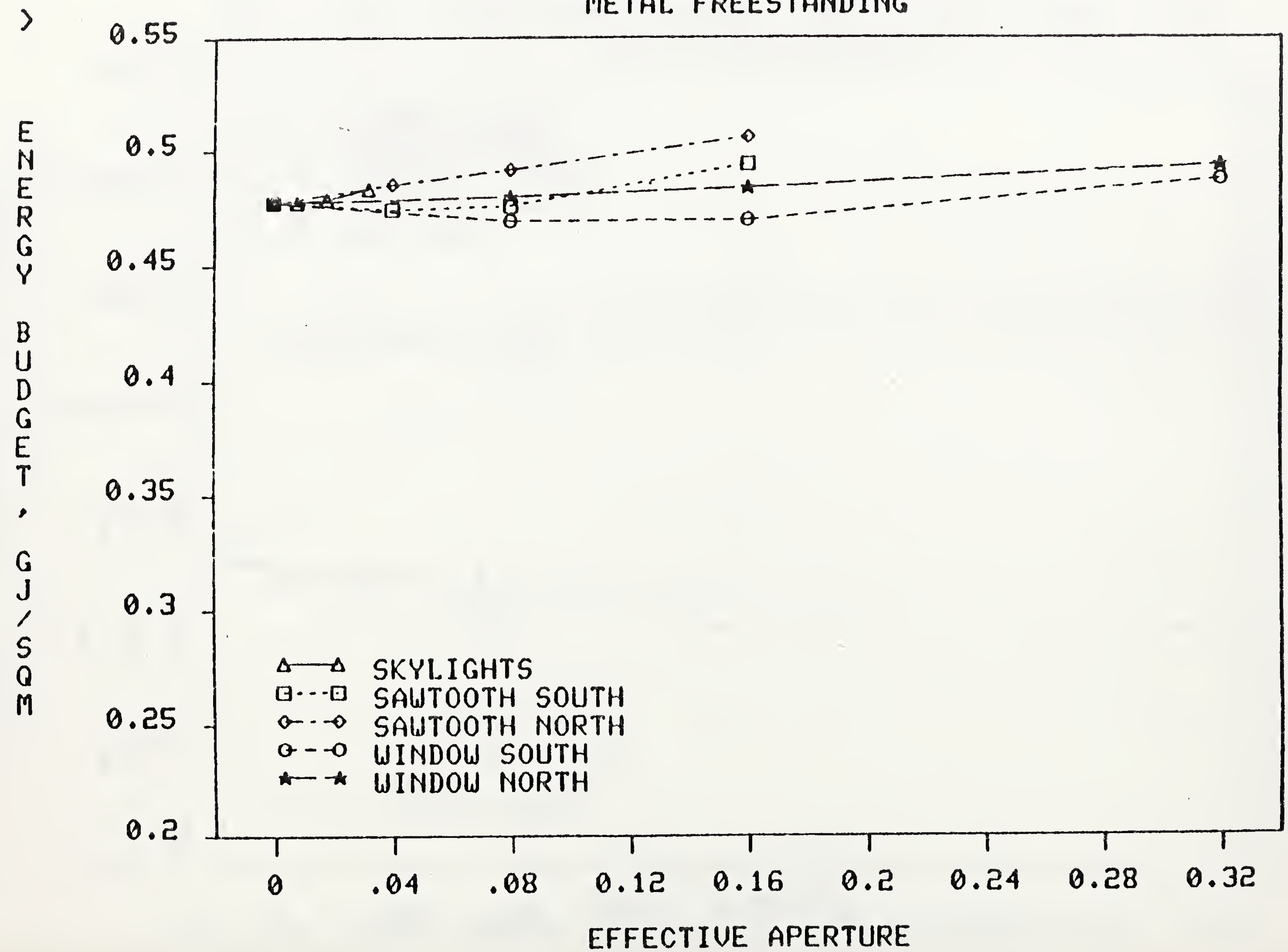


Figure 106. TOTAL ENERGY WITHOUT DAYLIGHT (San Diego) METAL ATTACHED

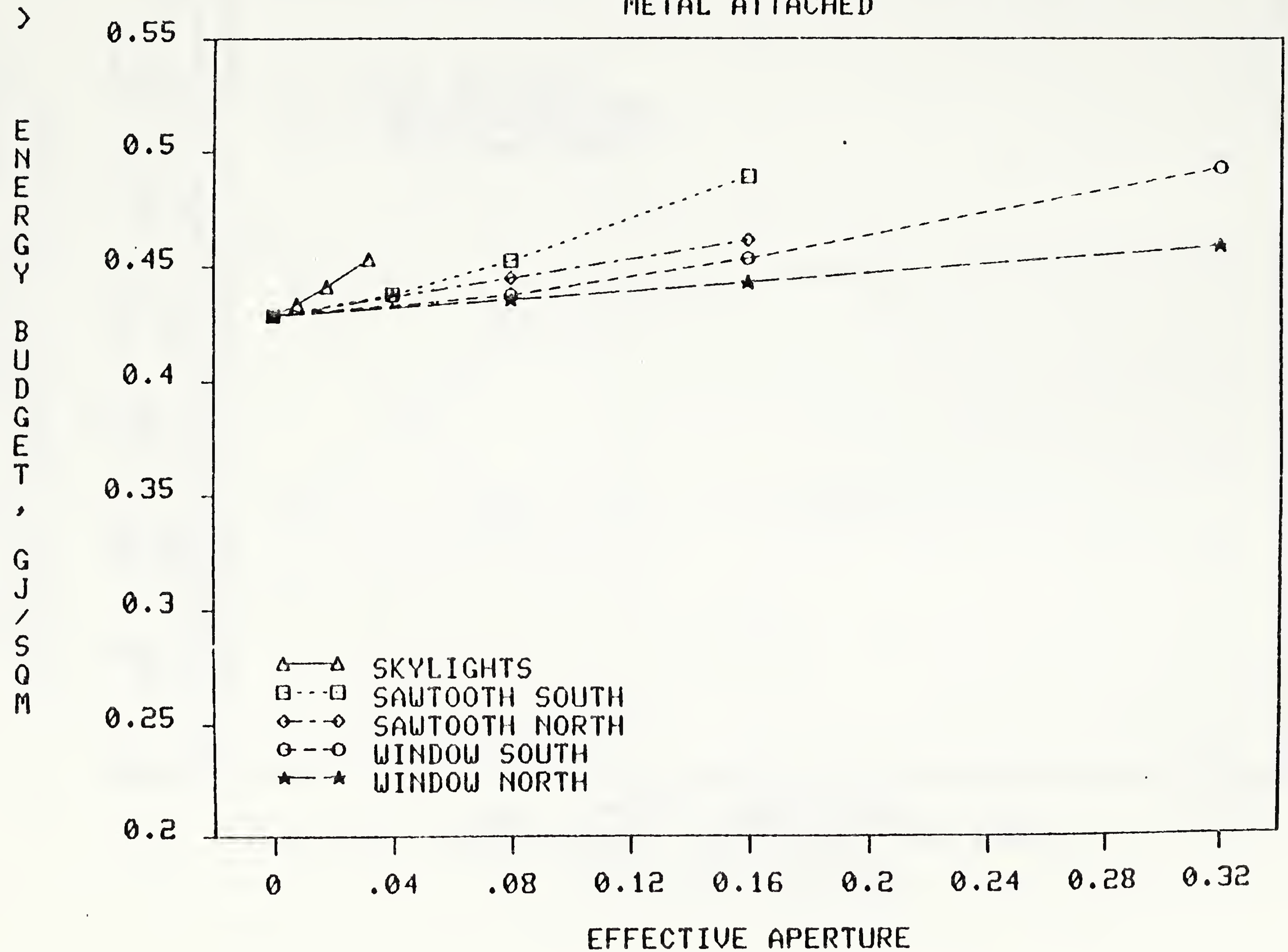


Figure 107. TOTAL ENERGY - SKYLIGHTS (San Diego)
BRICK FREESTANDING

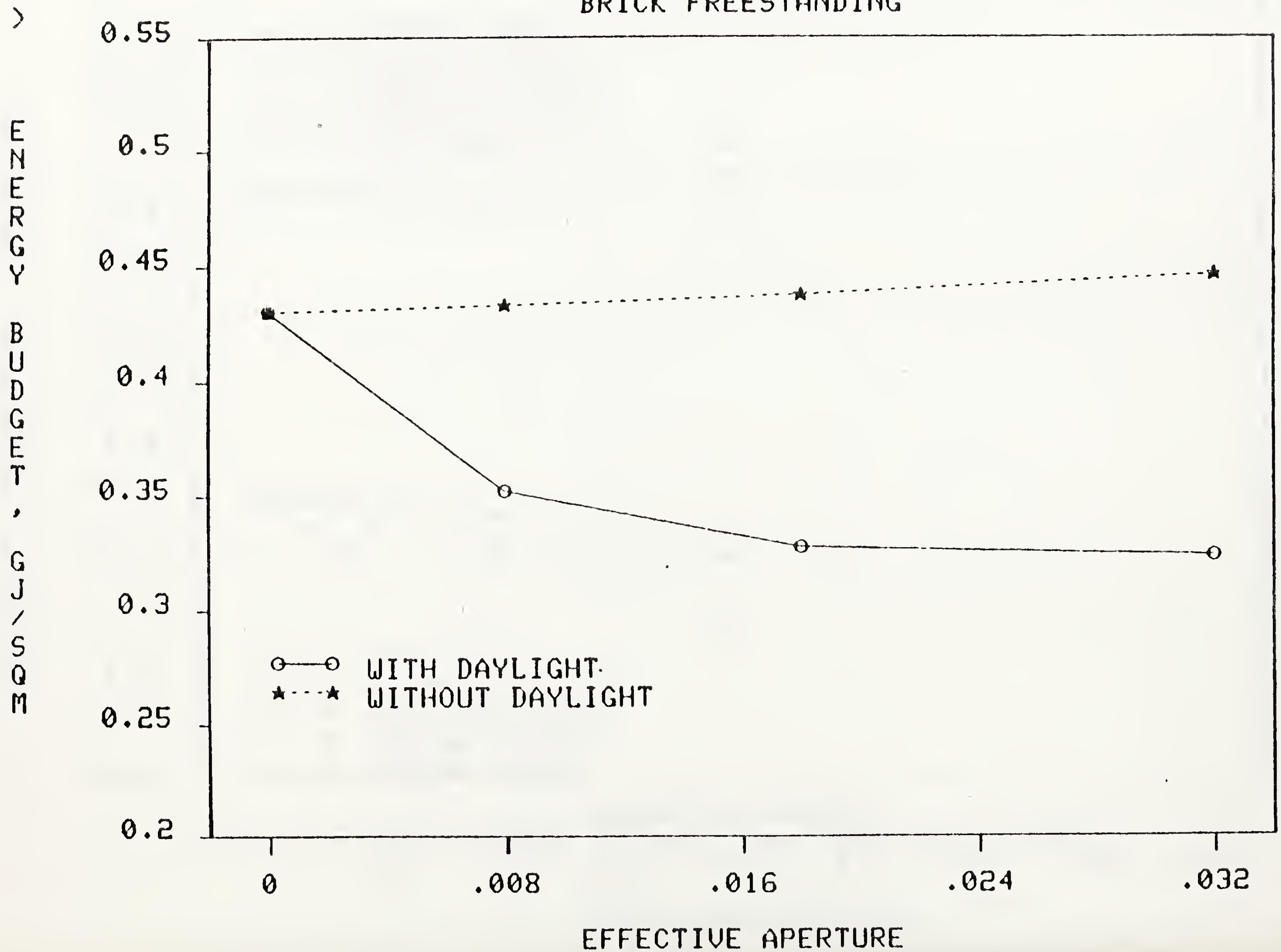


Figure 108. TOTAL ENERGY - SOUTH SAWTOOTH (San Diego)
BRICK FREESTANDING

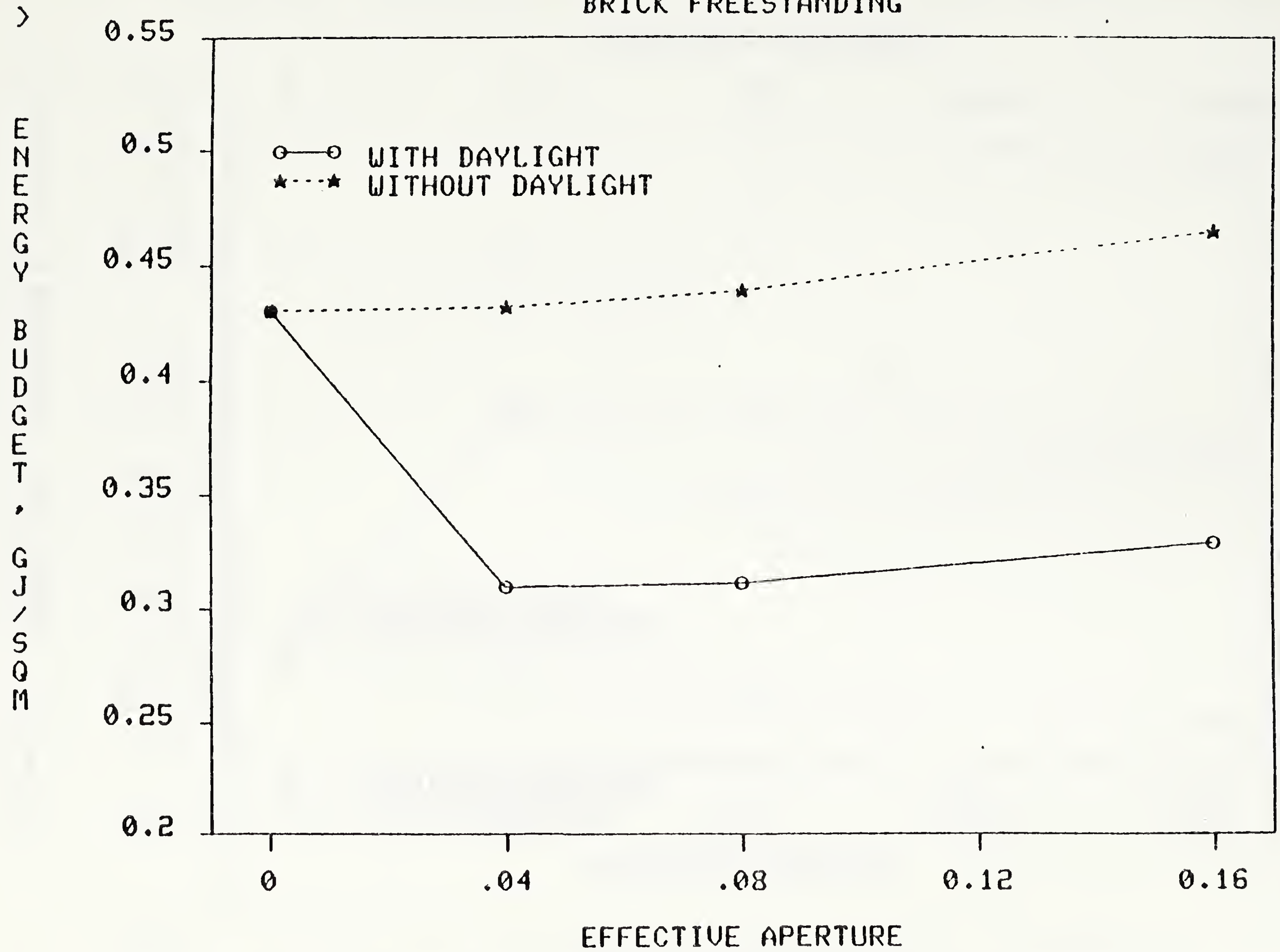


Figure 109. TOTAL ENERGY - NORTH SAWTOOTH (San Diego)
BRICK FREESTANDING

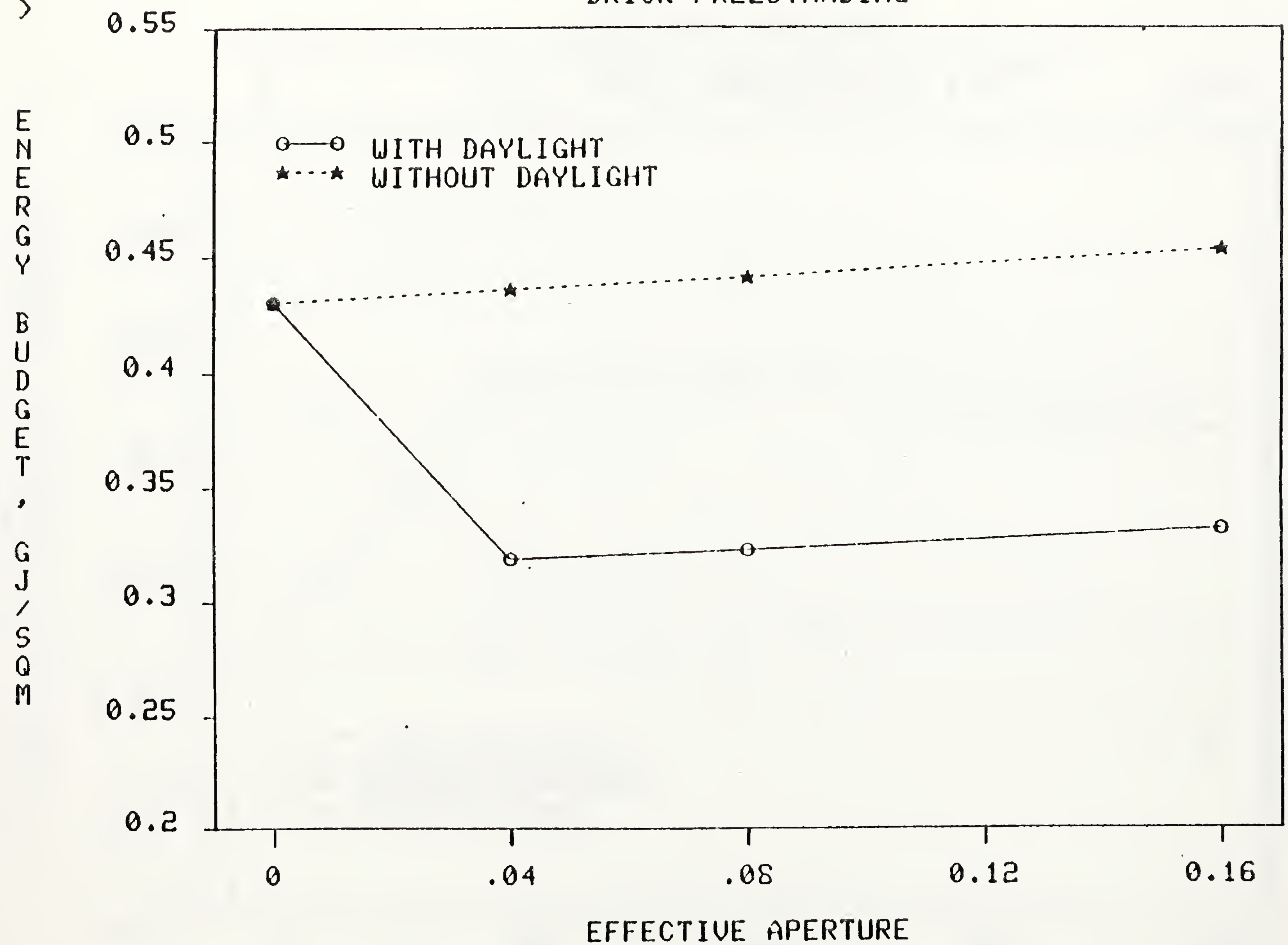


Figure 110. TOTAL ENERGY -- SOUTH WINDOW (San Diego)
BRICK FREESTANDING

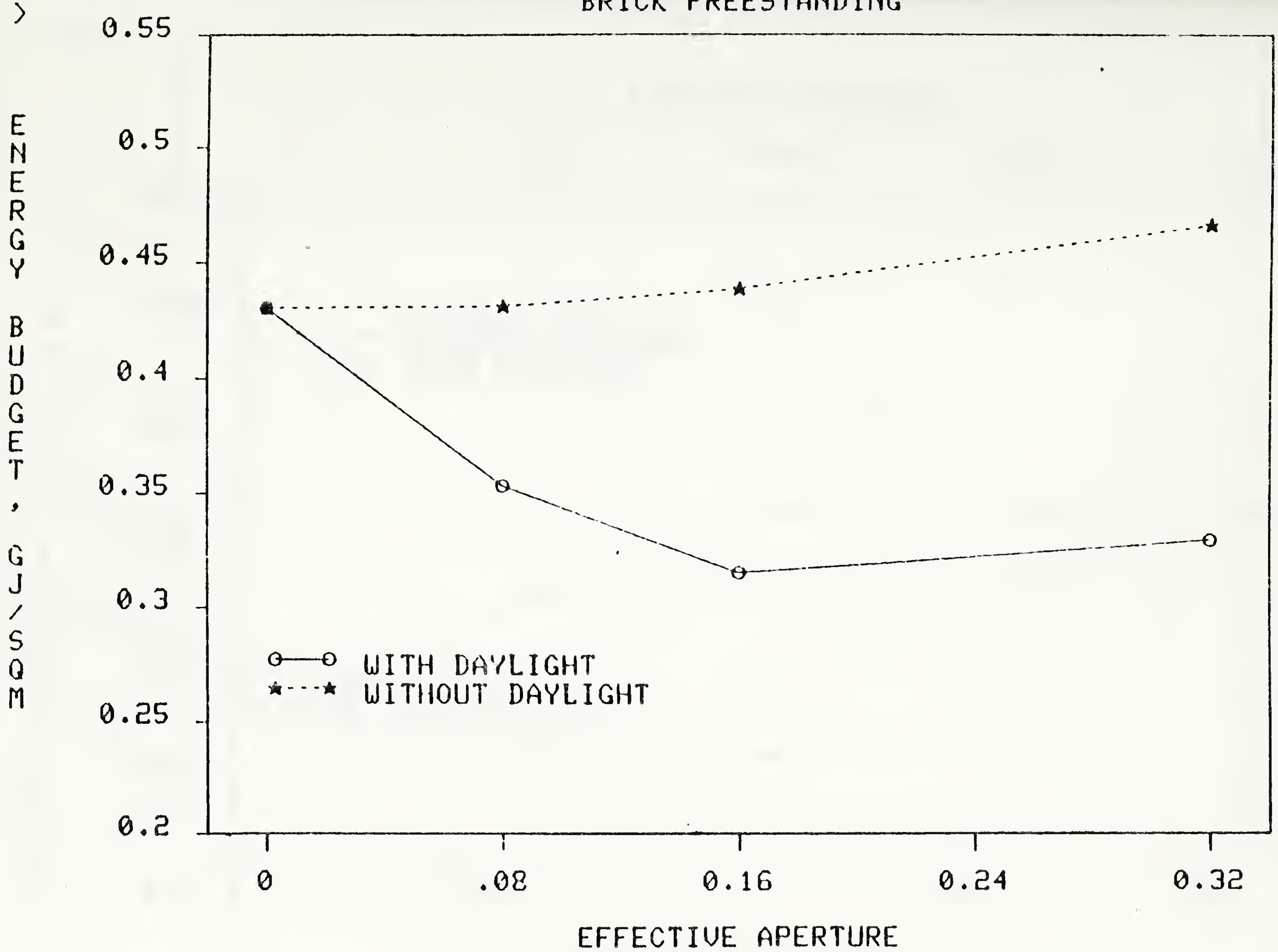


Figure 111. TOTAL ENERGY - NORTH WINDOW (San Diego)
BRICK FREESTANDING

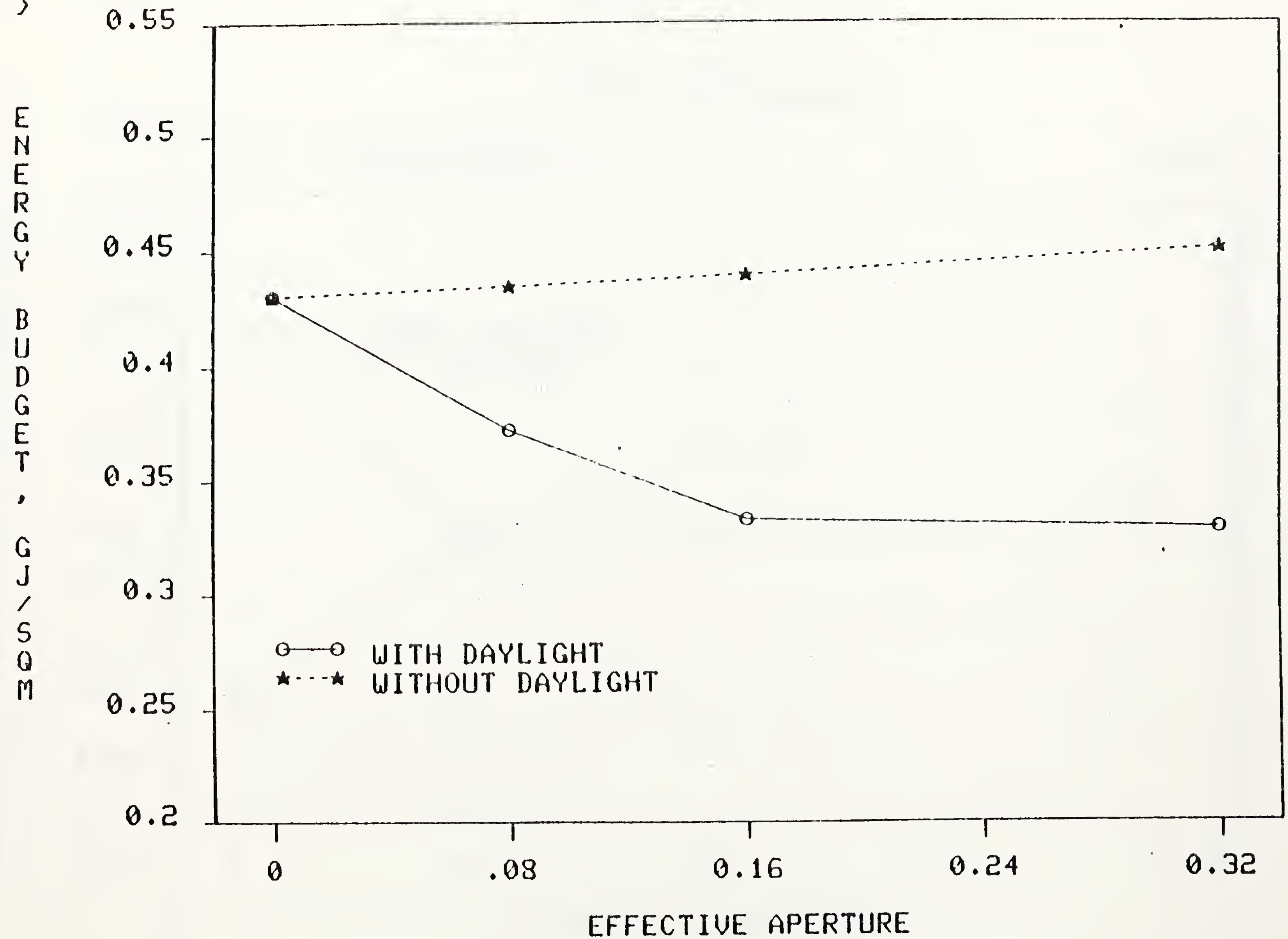


Figure 112 TOTAL ENERGY - SKYLIGHTS (San Diego)
BRICK ATTACHED

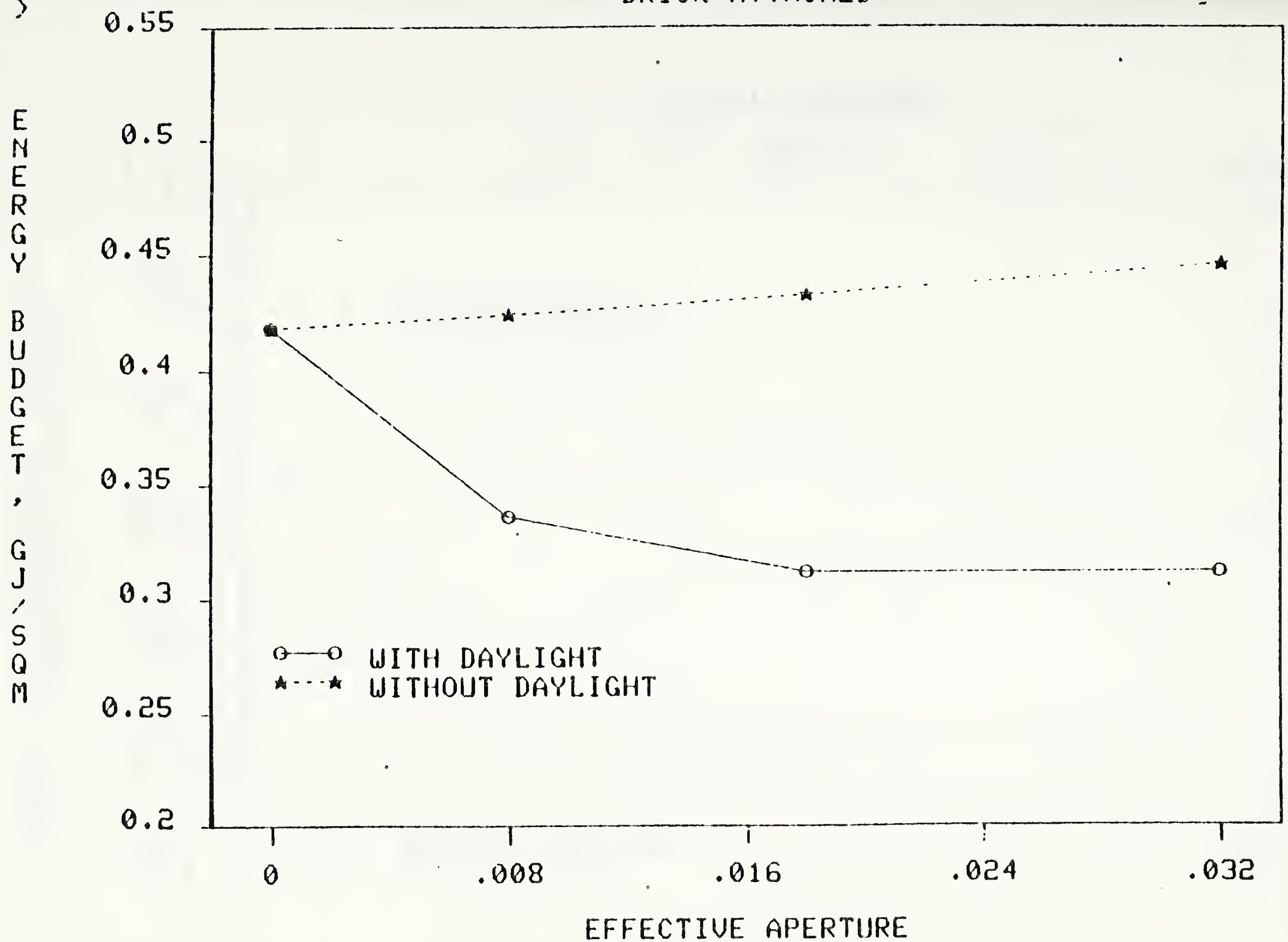


Figure 113. TOTAL ENERGY - SOUTH SAWTOOTH (San Diego)
BRICK ATTACHED

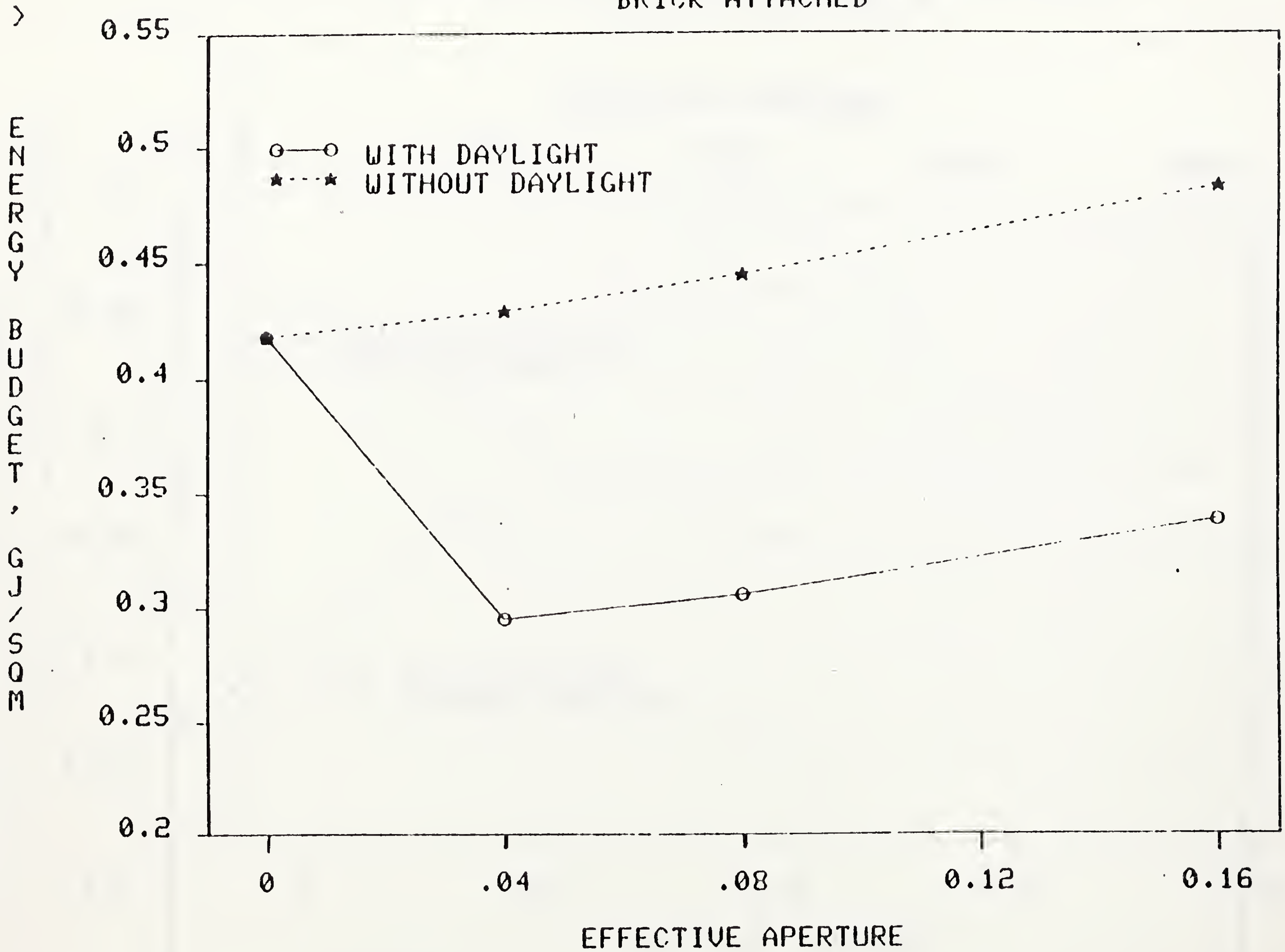


Figure 114. TOTAL ENERGY - NORTH SAWTOOTH (San Diego)
BRICK ATTACHED

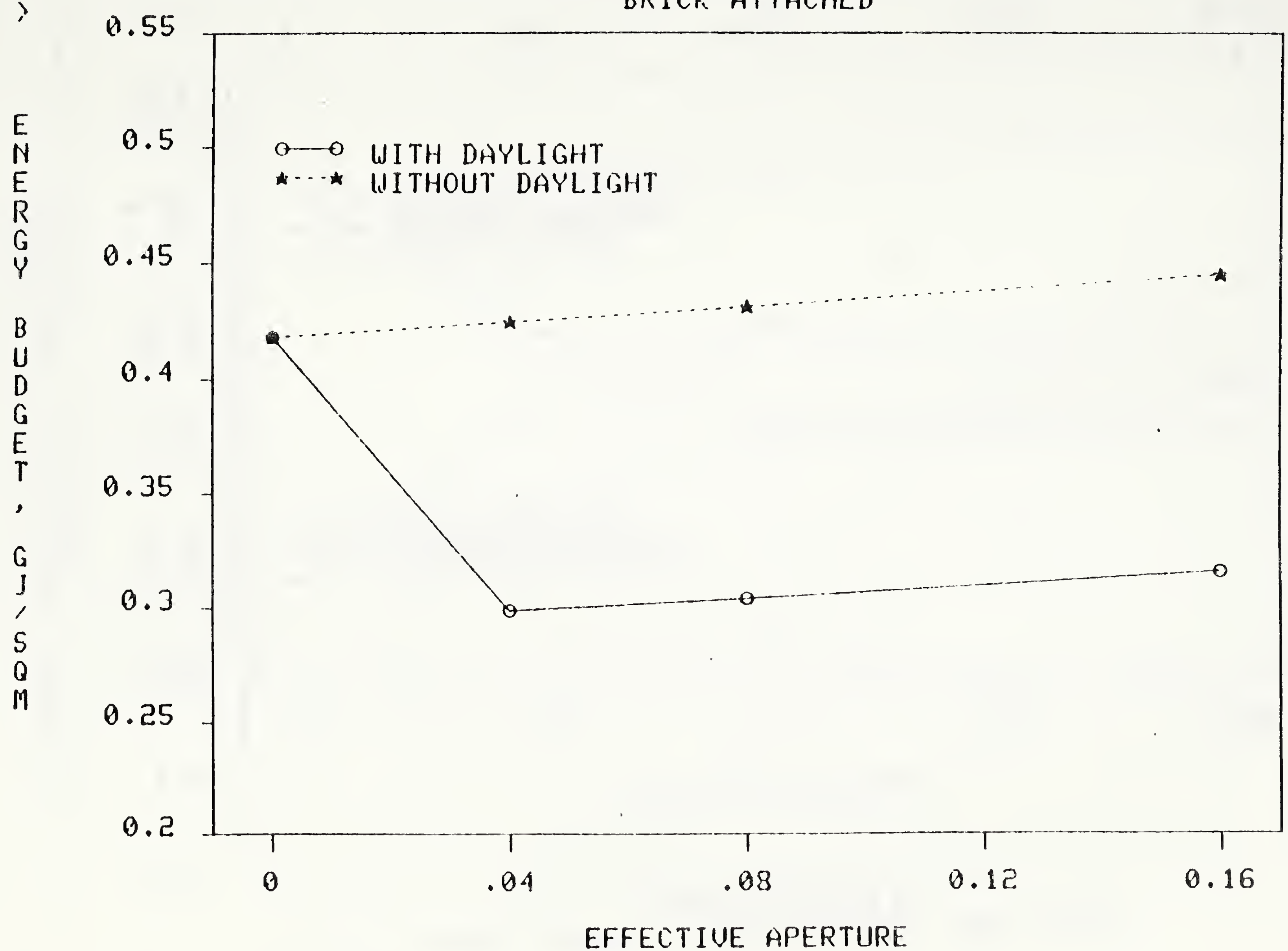


Figure 115. TOTAL ENERGY - SOUTH WINDOW (San Diego)
BRICK ATTACHED

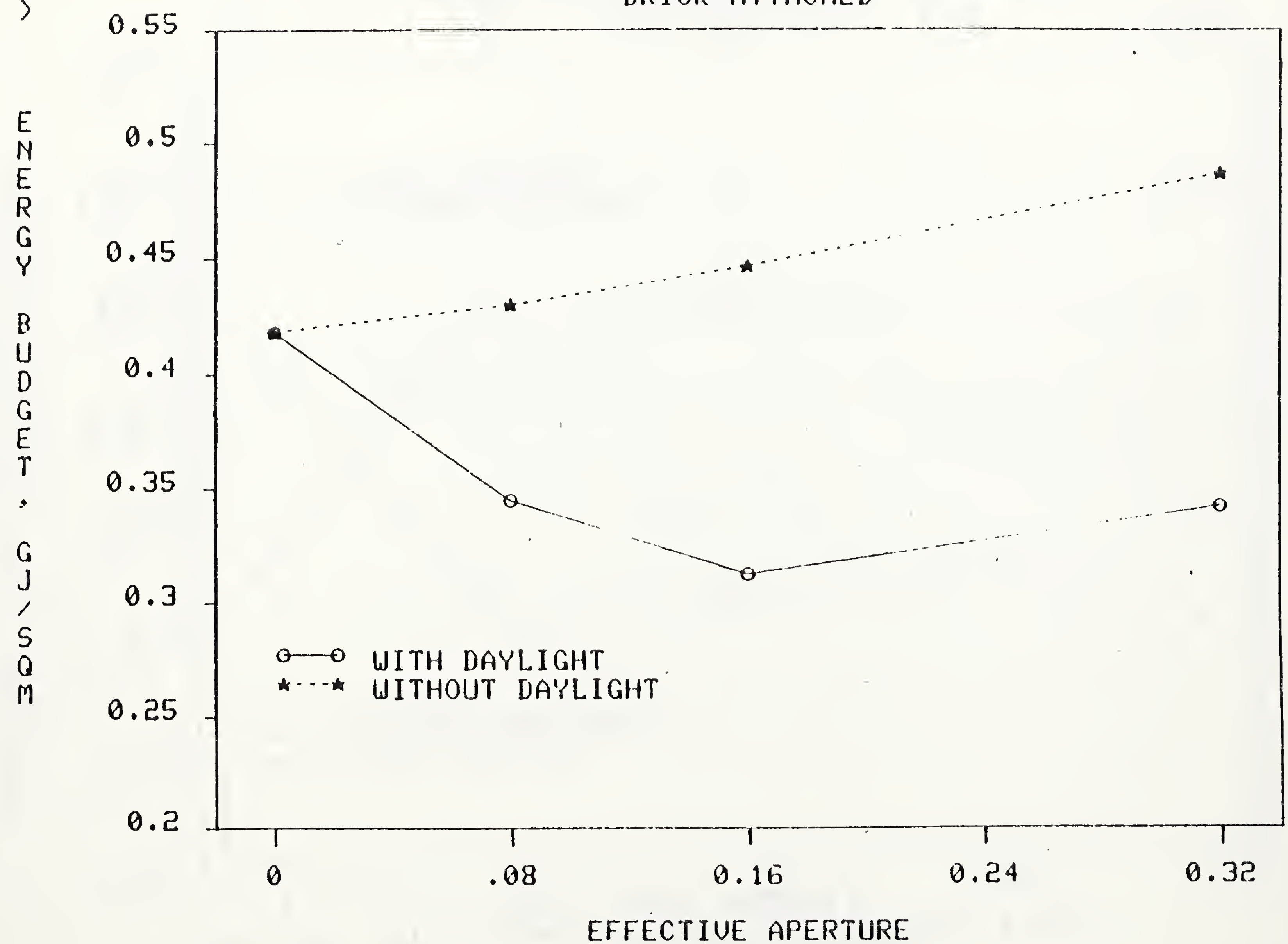


Figure 11... TOTAL ENERGY - NORTH WINDOW (San Diego)
BRICK ATTACHED

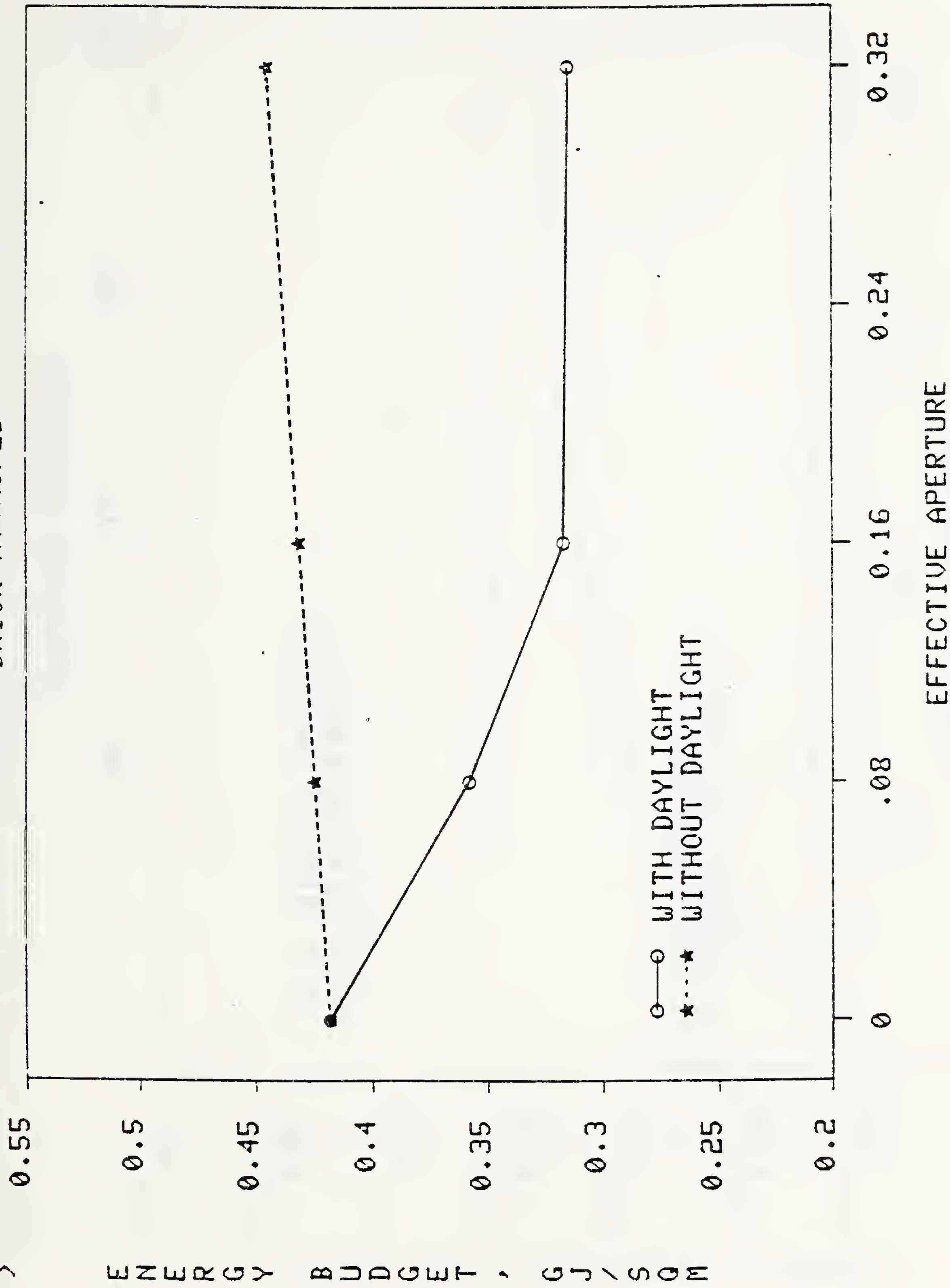
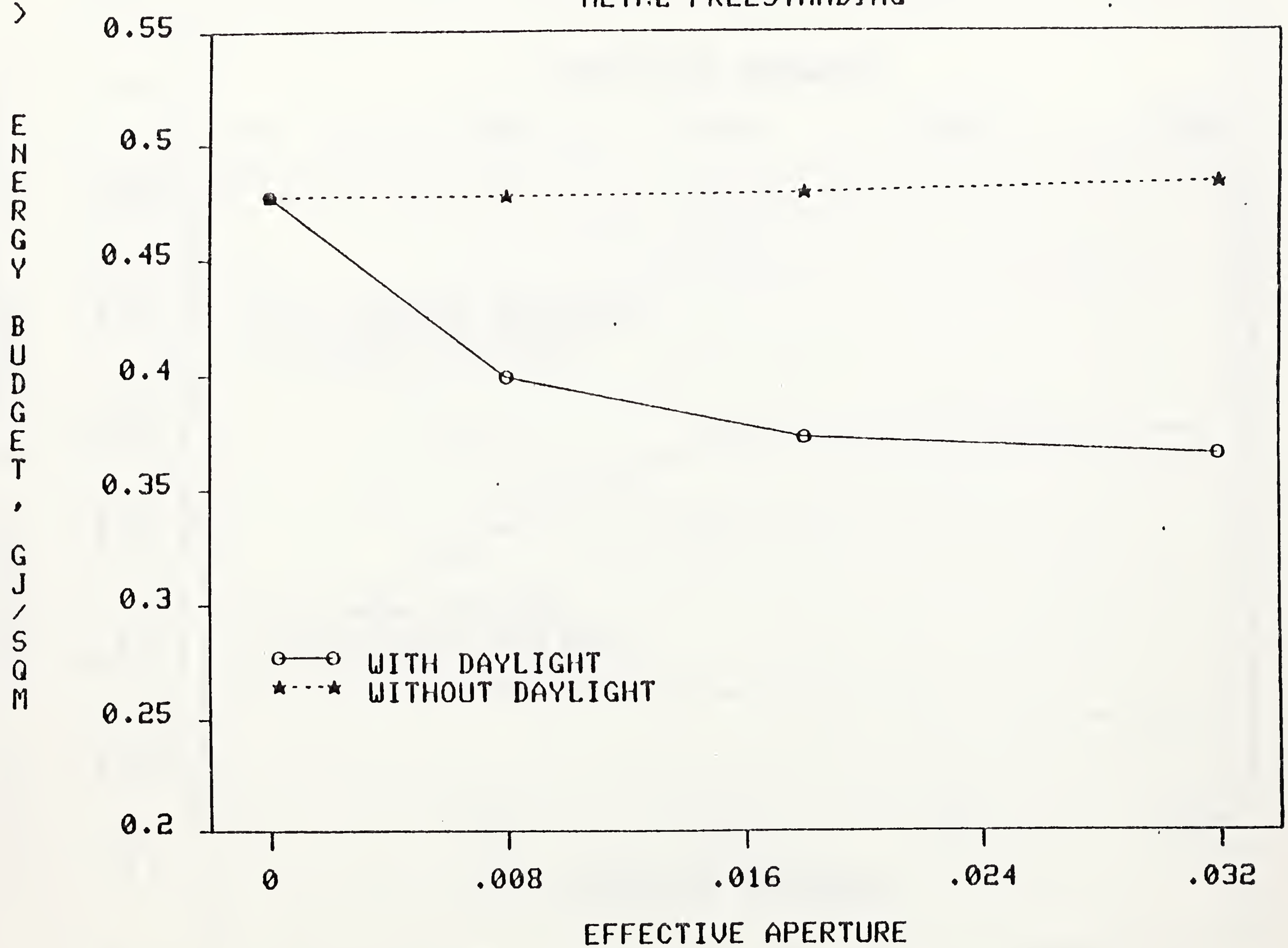


Figure 117 TOTAL ENERGY - SKYLIGHTS (San Diego)
METAL FREESTANDING



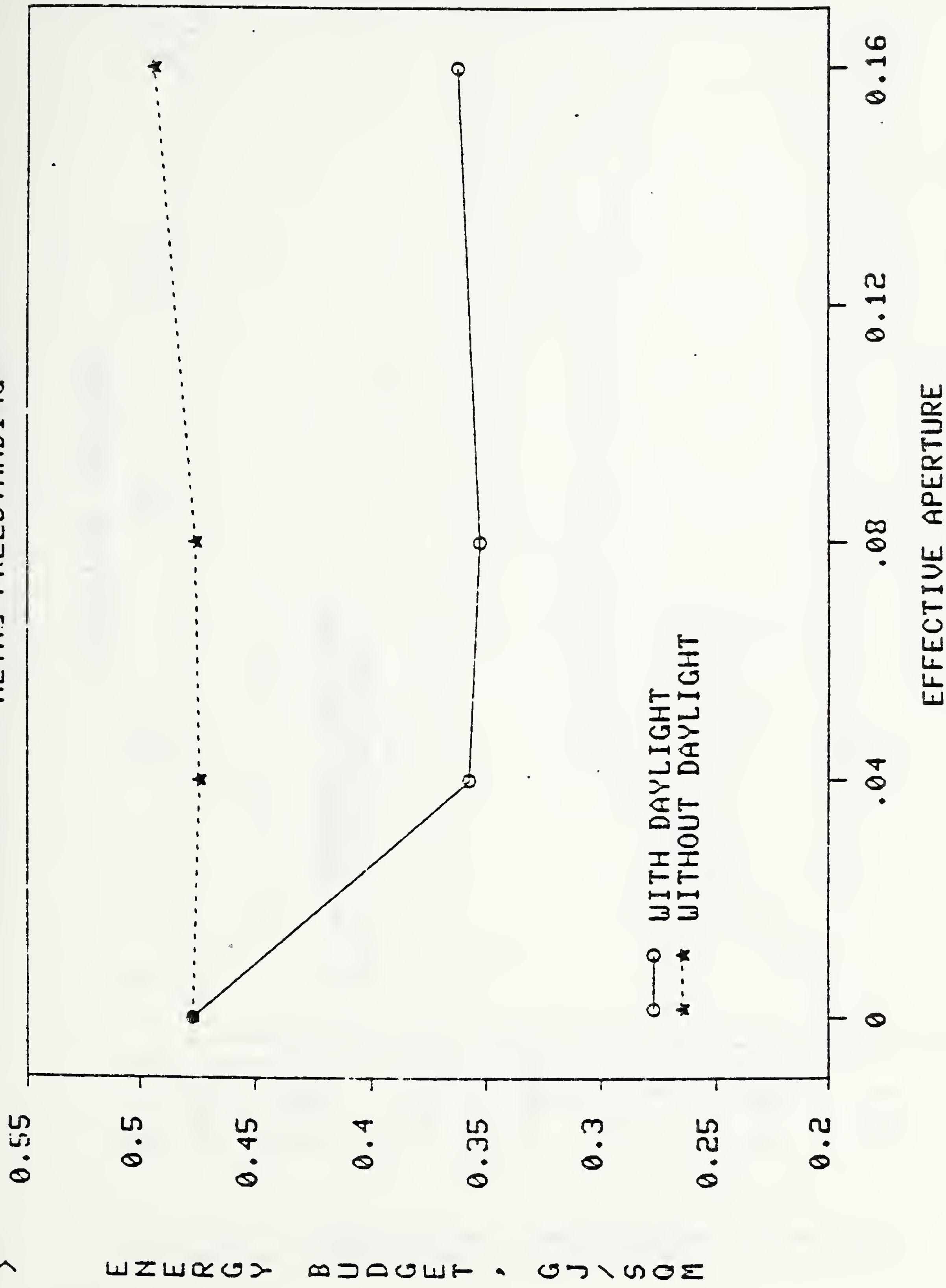



Figure 11[illegible]. TOTAL ENERGY - SOUTH SAWTOOTH (San Diego)
METAL FREESTANDING

Figure 119. TOTAL ENERGY - NORTH SAWTOOTH (San Diego)
METAL FREESTANDING

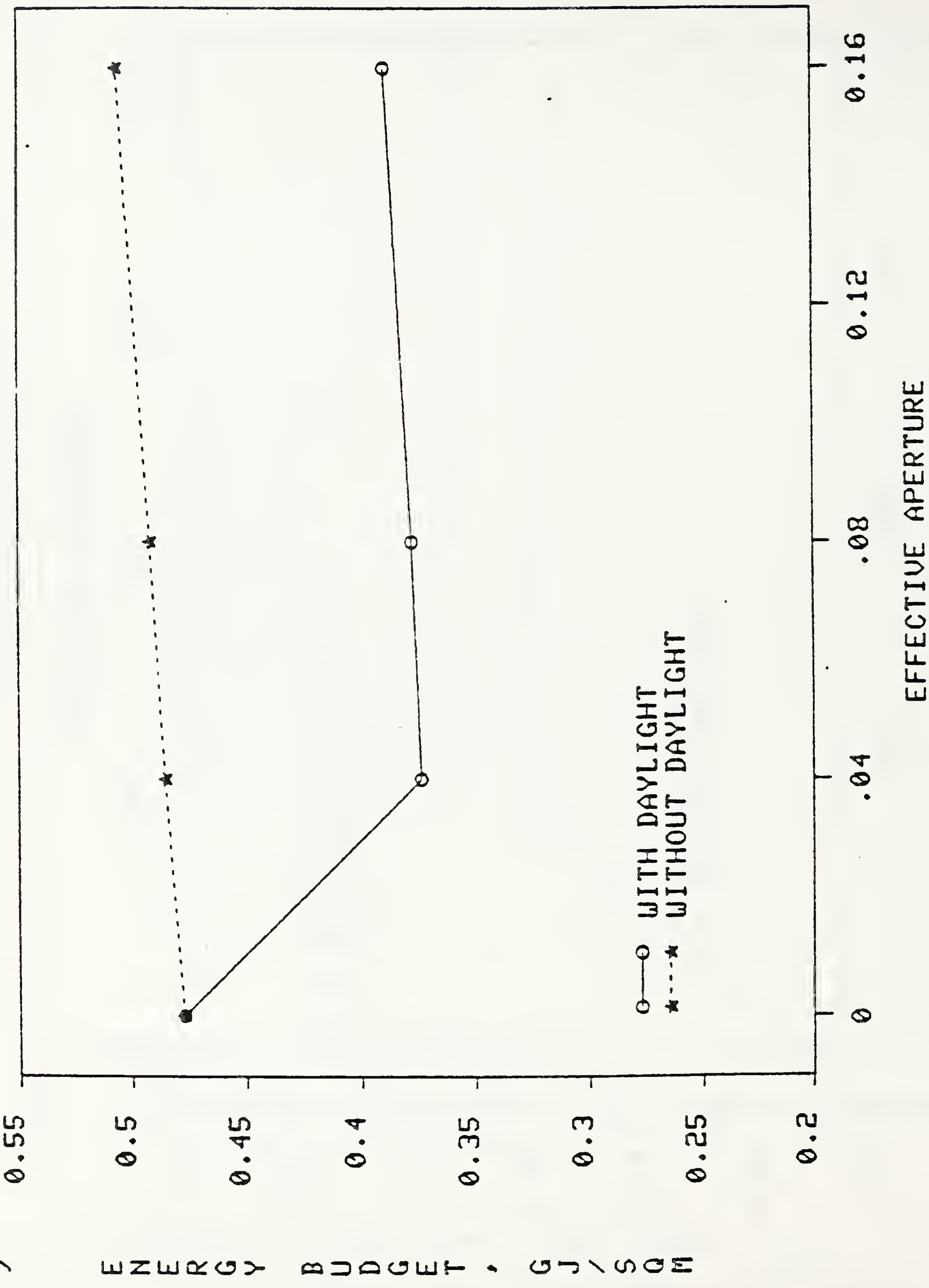


Figure 120. TOTAL ENERGY - SOUTH WINDOW (San Diego)
METAL FREESTANDING

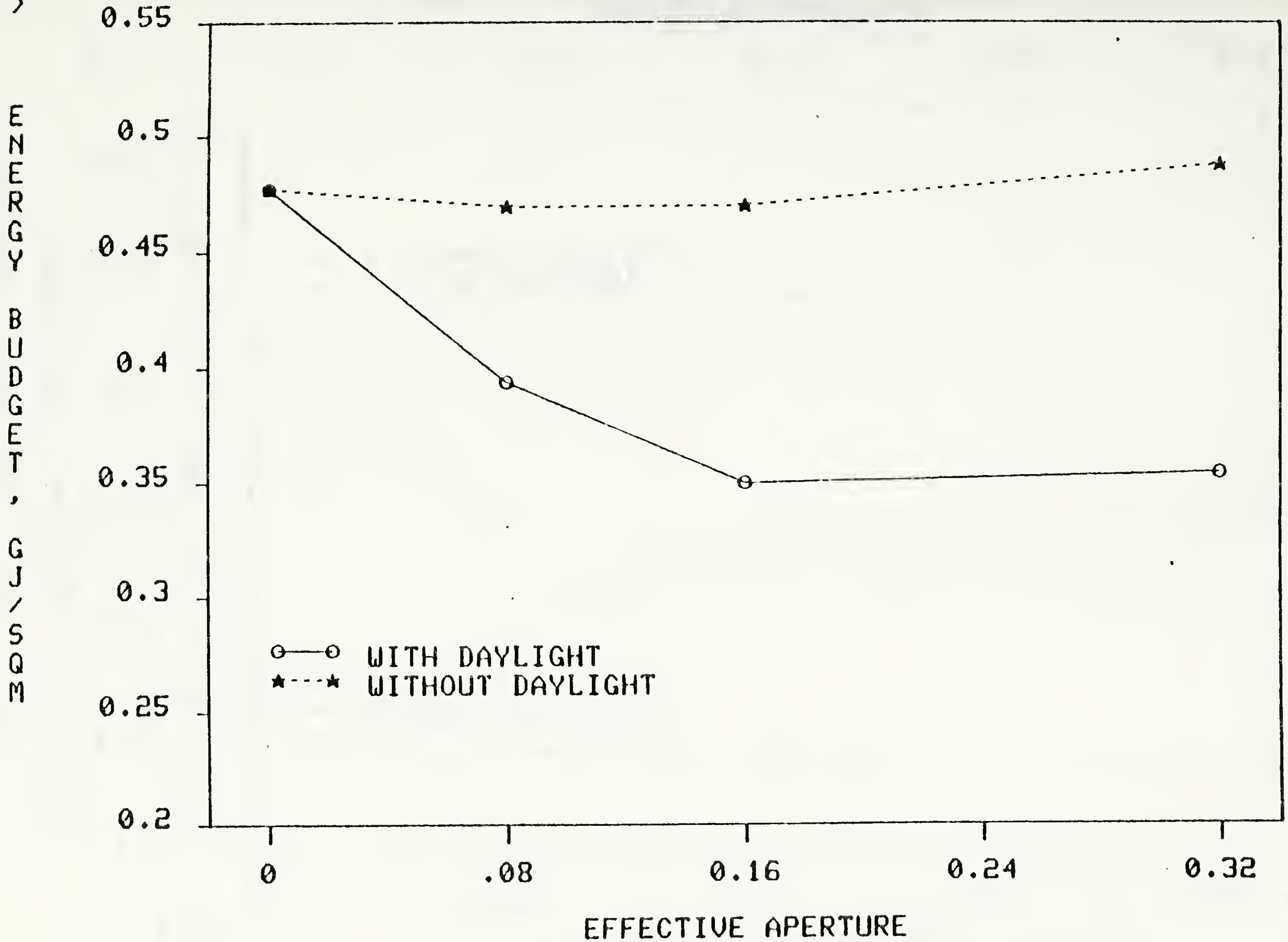


Figure 121. TOTAL ENERGY - NORTH WINDOW (San Diego)
METAL FREESTANDING

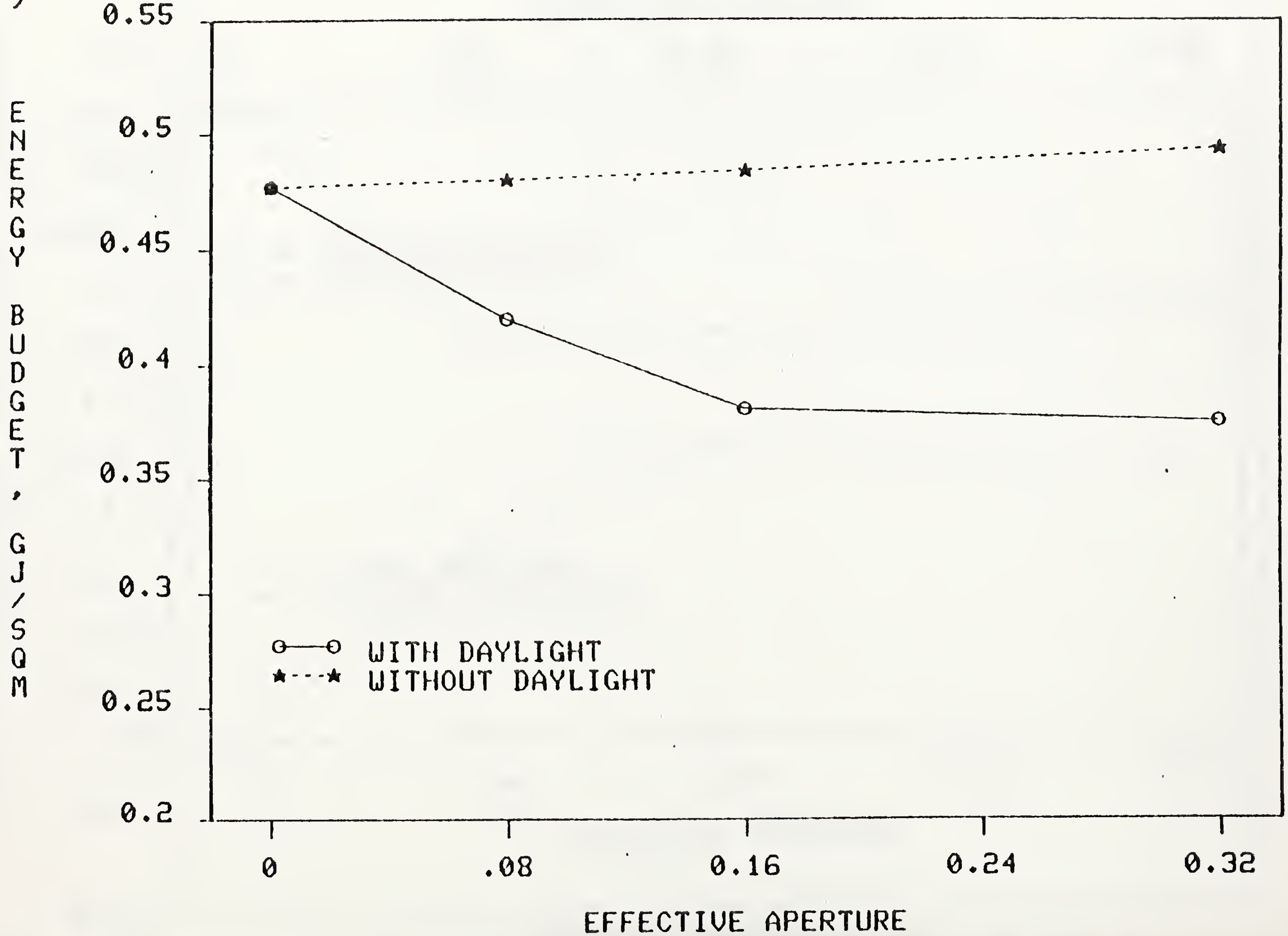


Figure 22. TOTAL ENERGY -- SKYLIGHTS (San Diego)
METAL ATTACHED

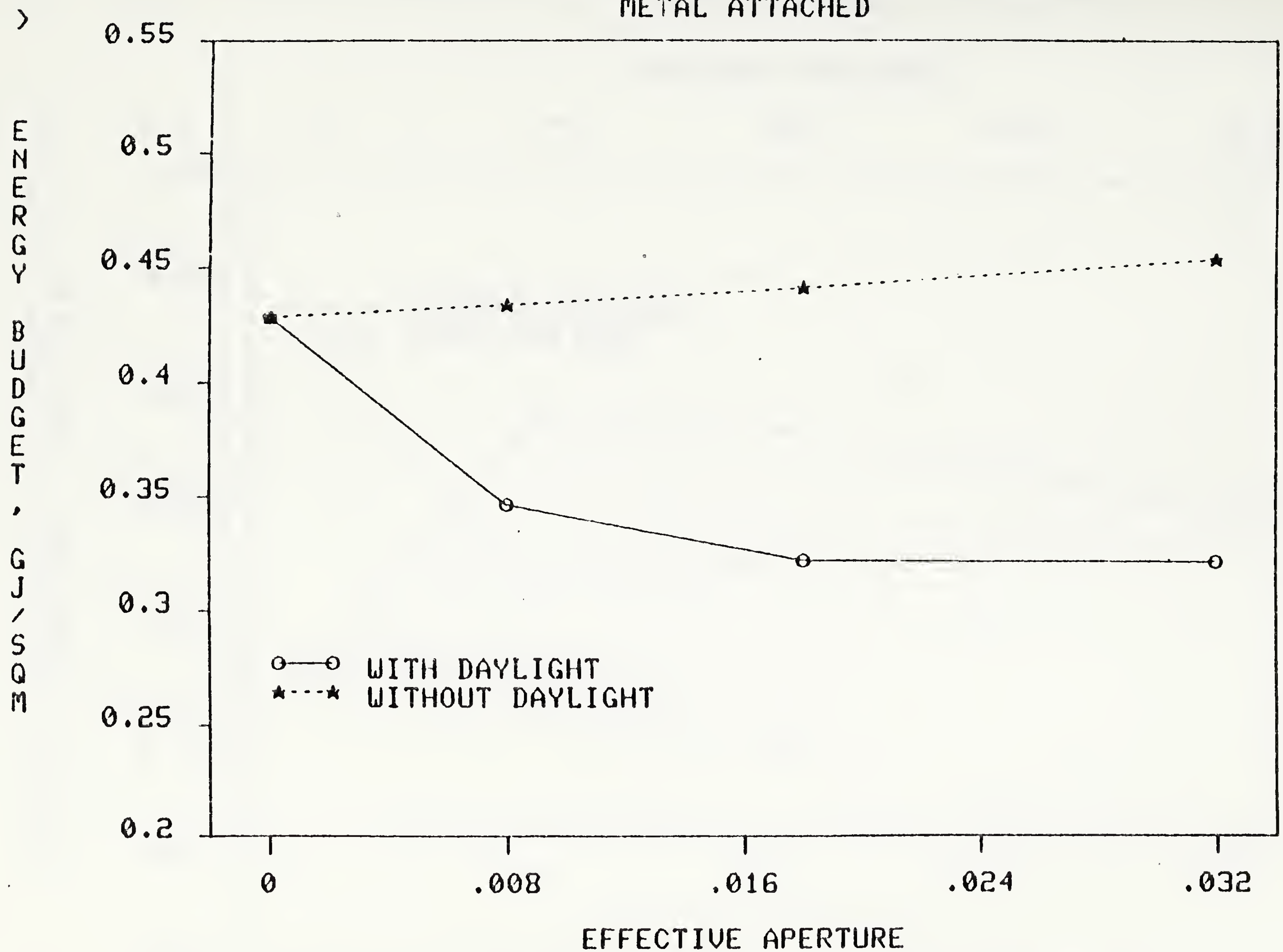


Figure 123. TOTAL ENERGY - SOUTH SAWTOOTH (San Diego)
METAL ATTACHED

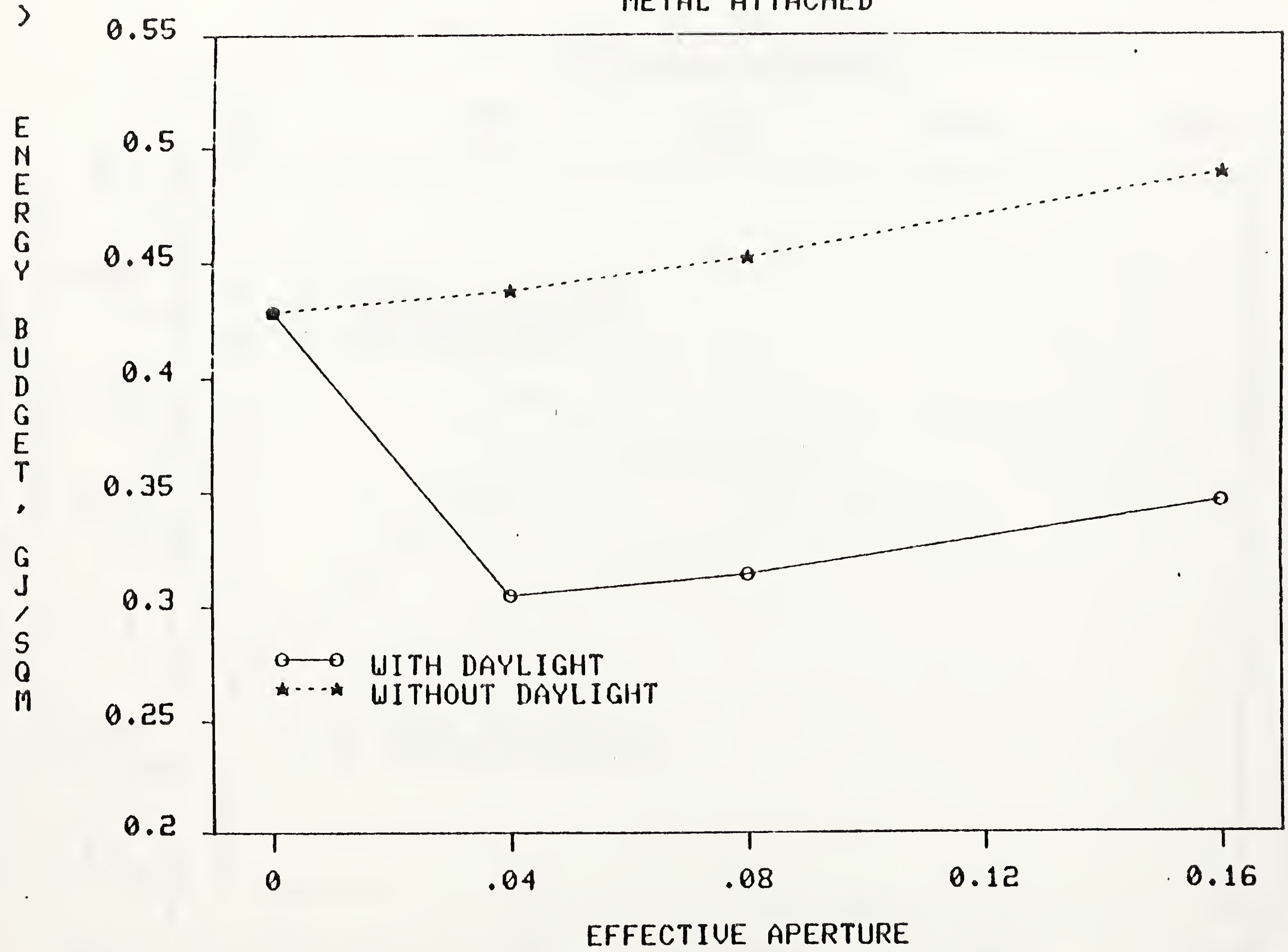


Figure 124. TOTAL ENERGY - NORTH SAWTOOTH (San Diego) METAL ATTACHED

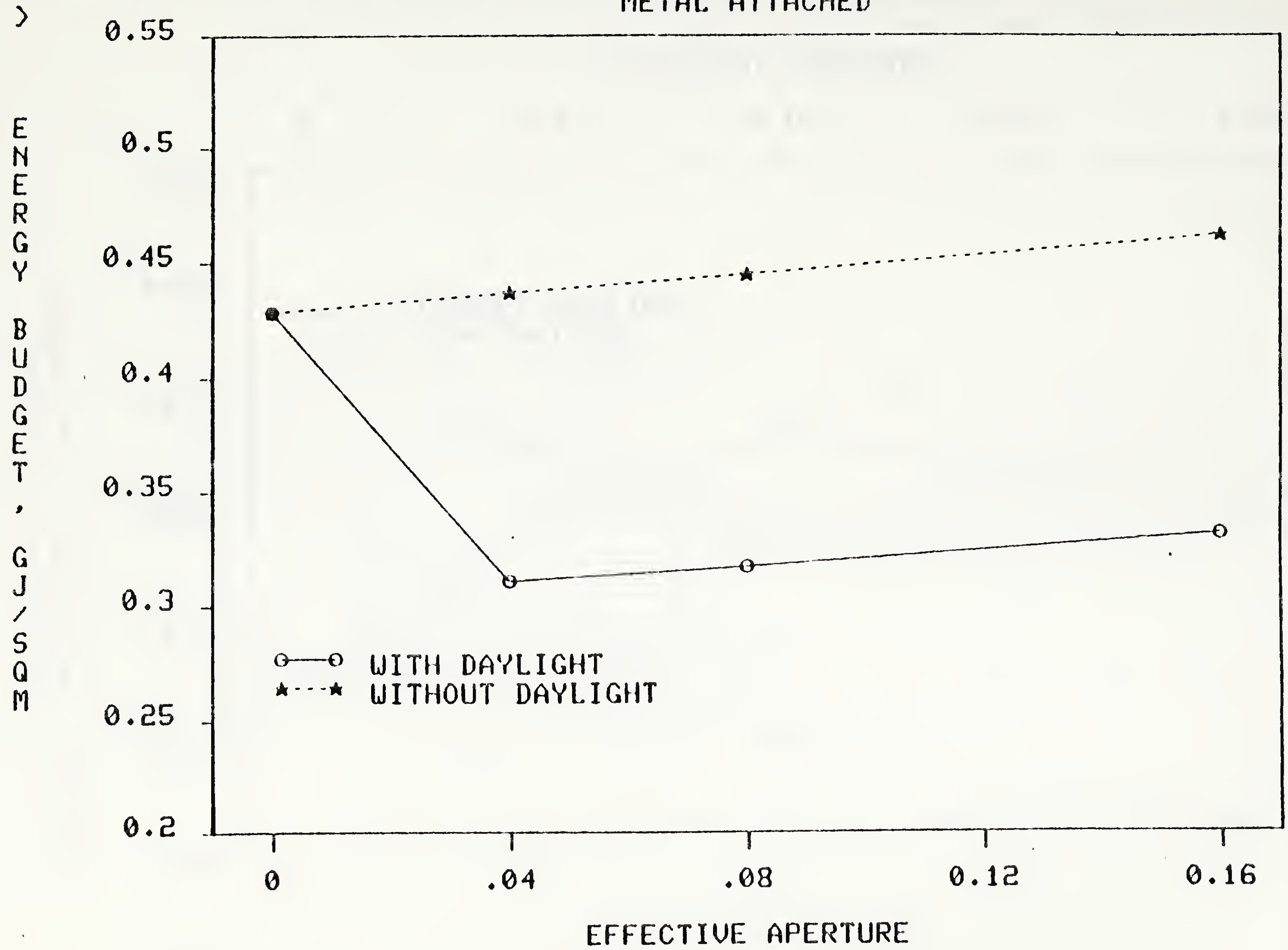


Figure 125. TOTAL ENERGY - SOUTH WINDOW (San Diego) METAL ATTACHED

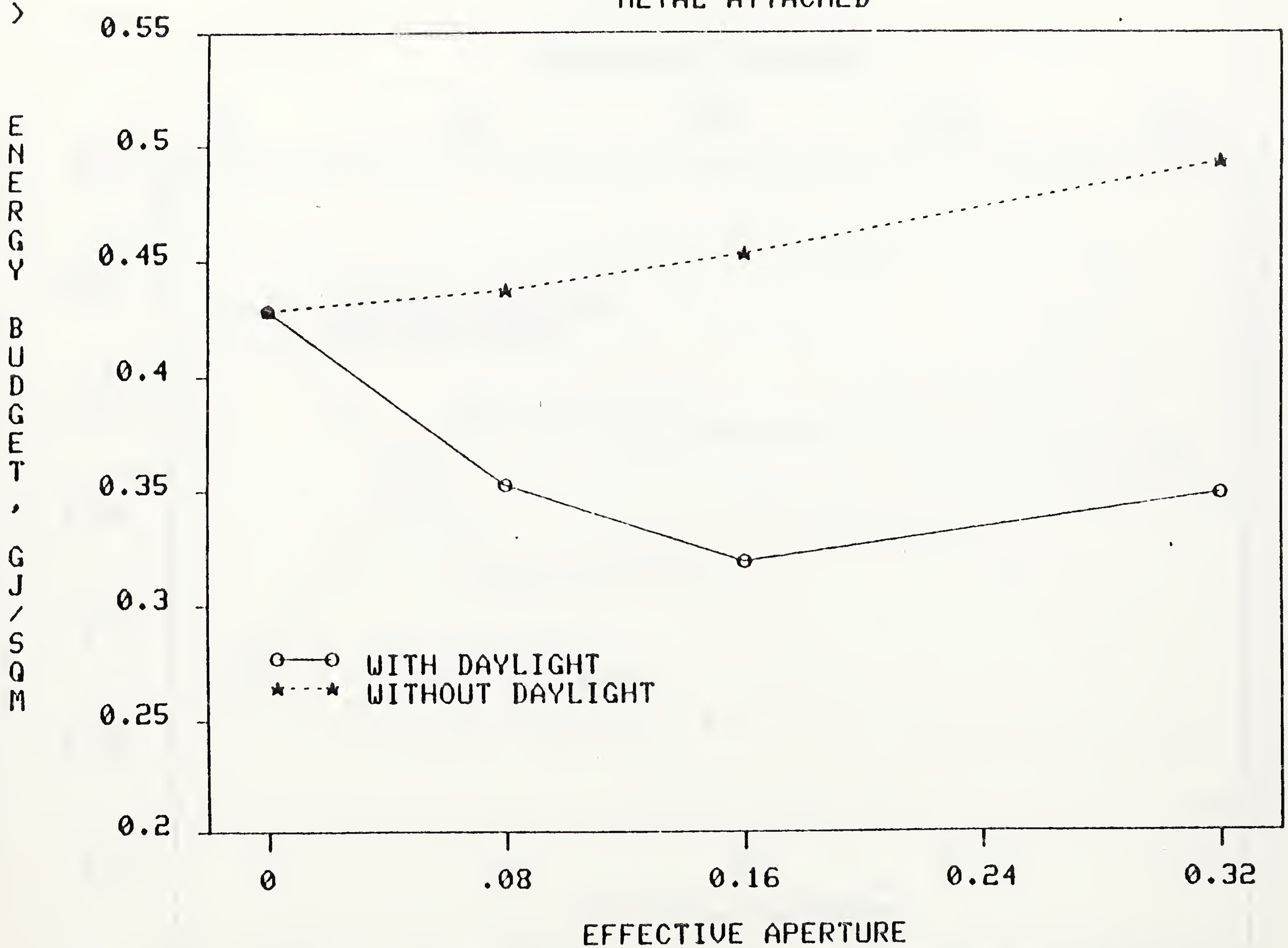


Figure 126. TOTAL ENERGY - NORTH WINDOW (San Diego)
METAL ATTACHED

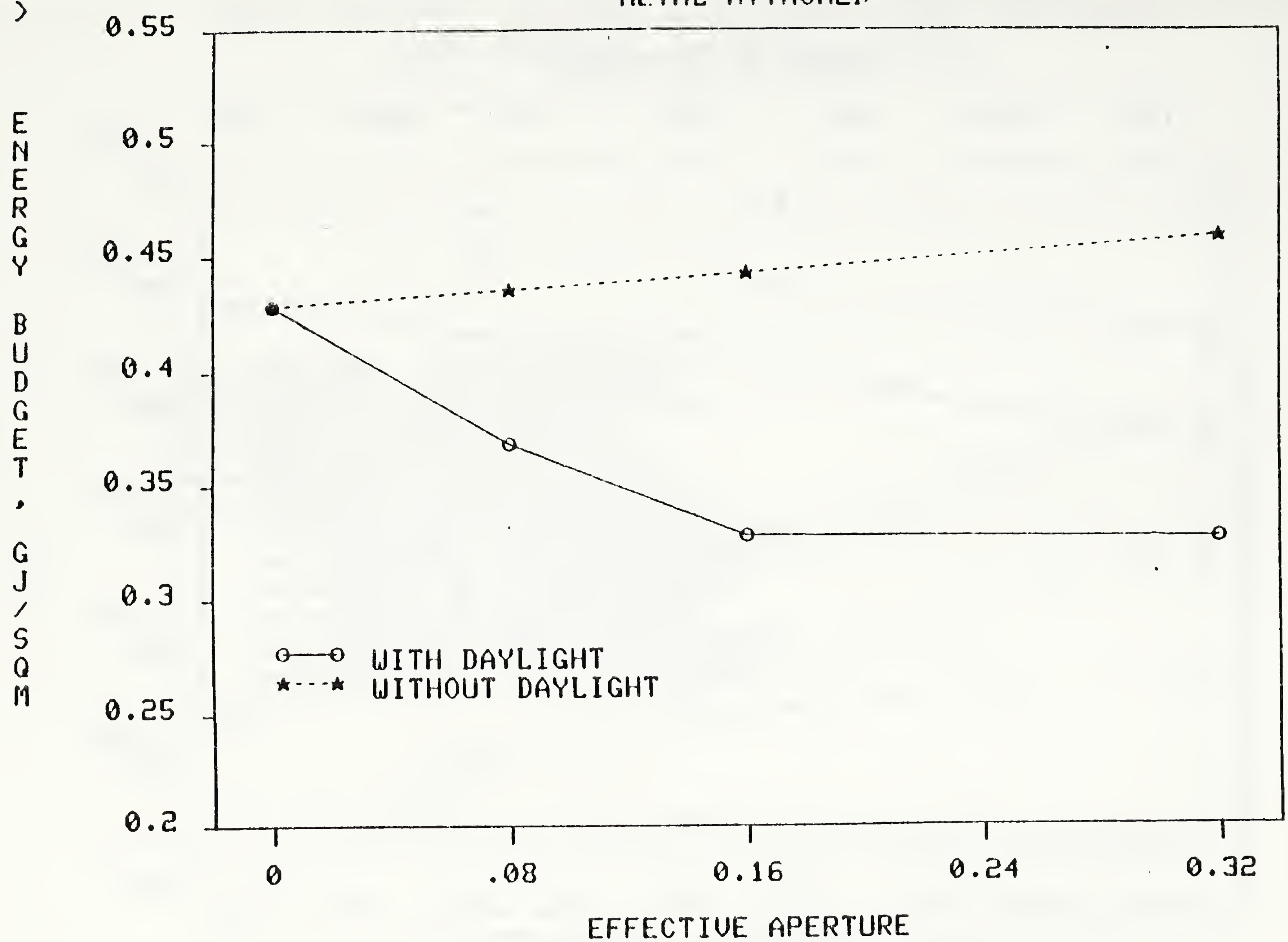


Figure 127. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
SKYLIGHTS, BRICK FREESTANDING

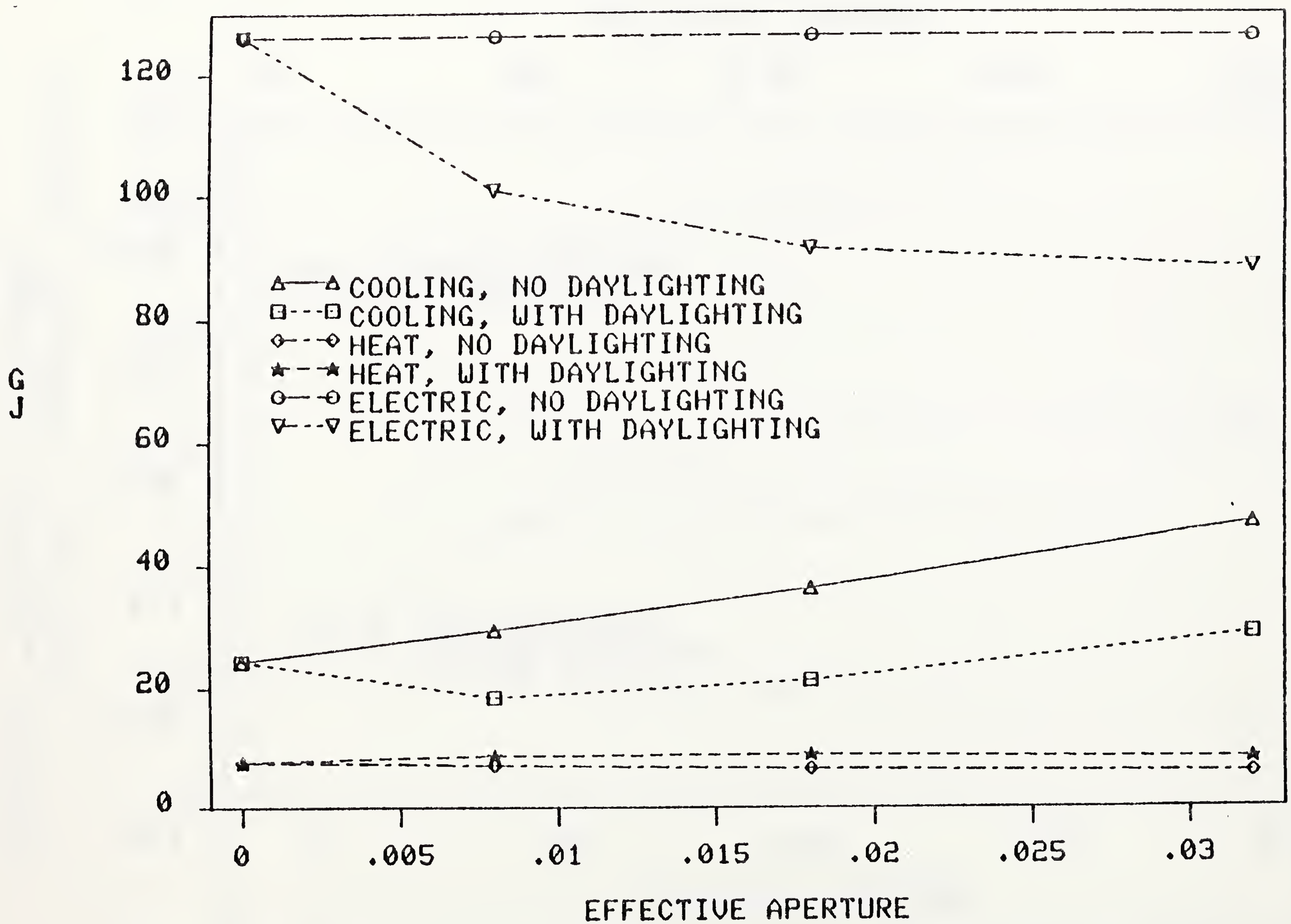


Figure 123. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego) SOUTH SAWTOOTH, BRICK FREESTANDING

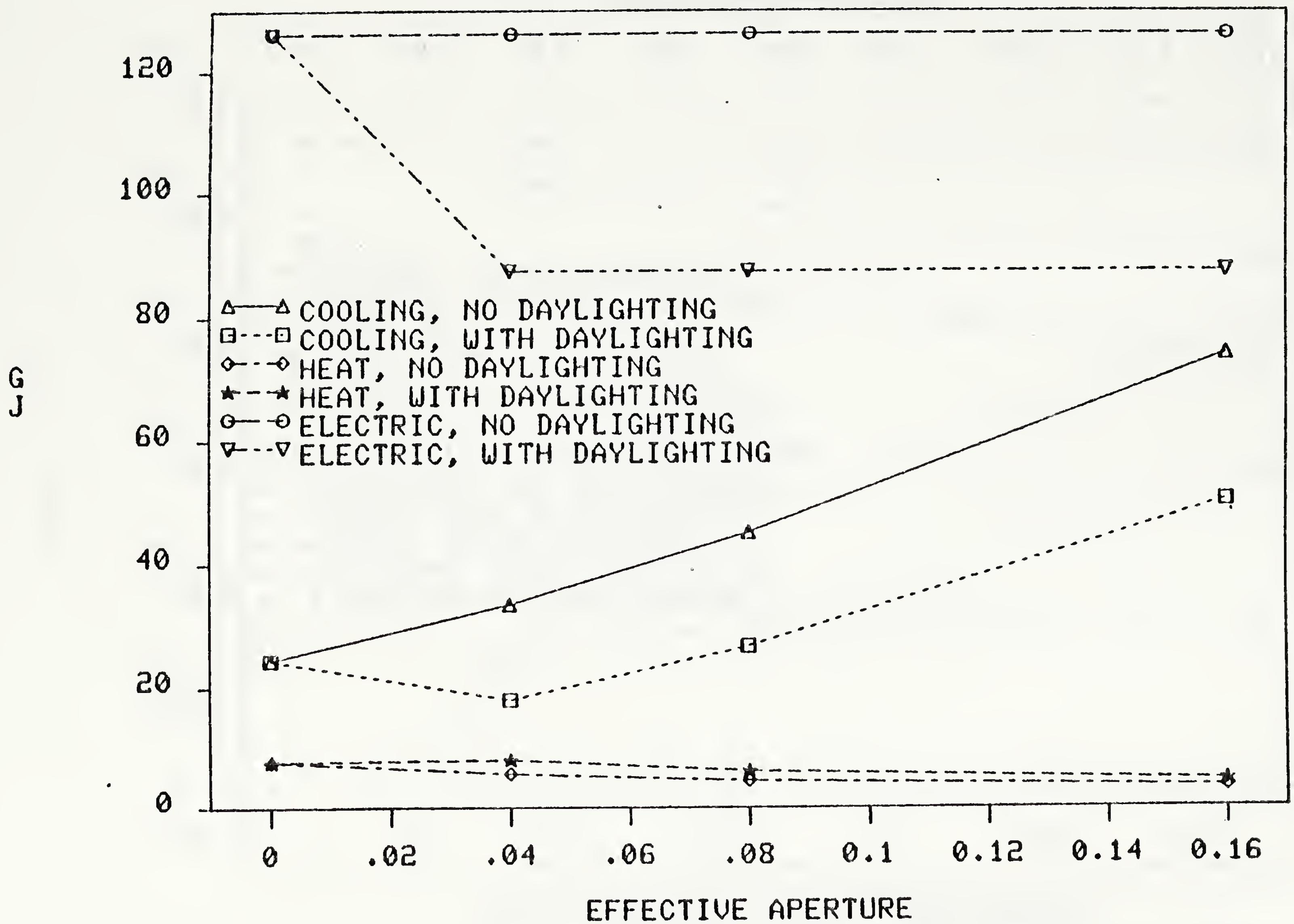


Figure 129. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
NORTH SAWTOOTH, BRICK FREESTANDING

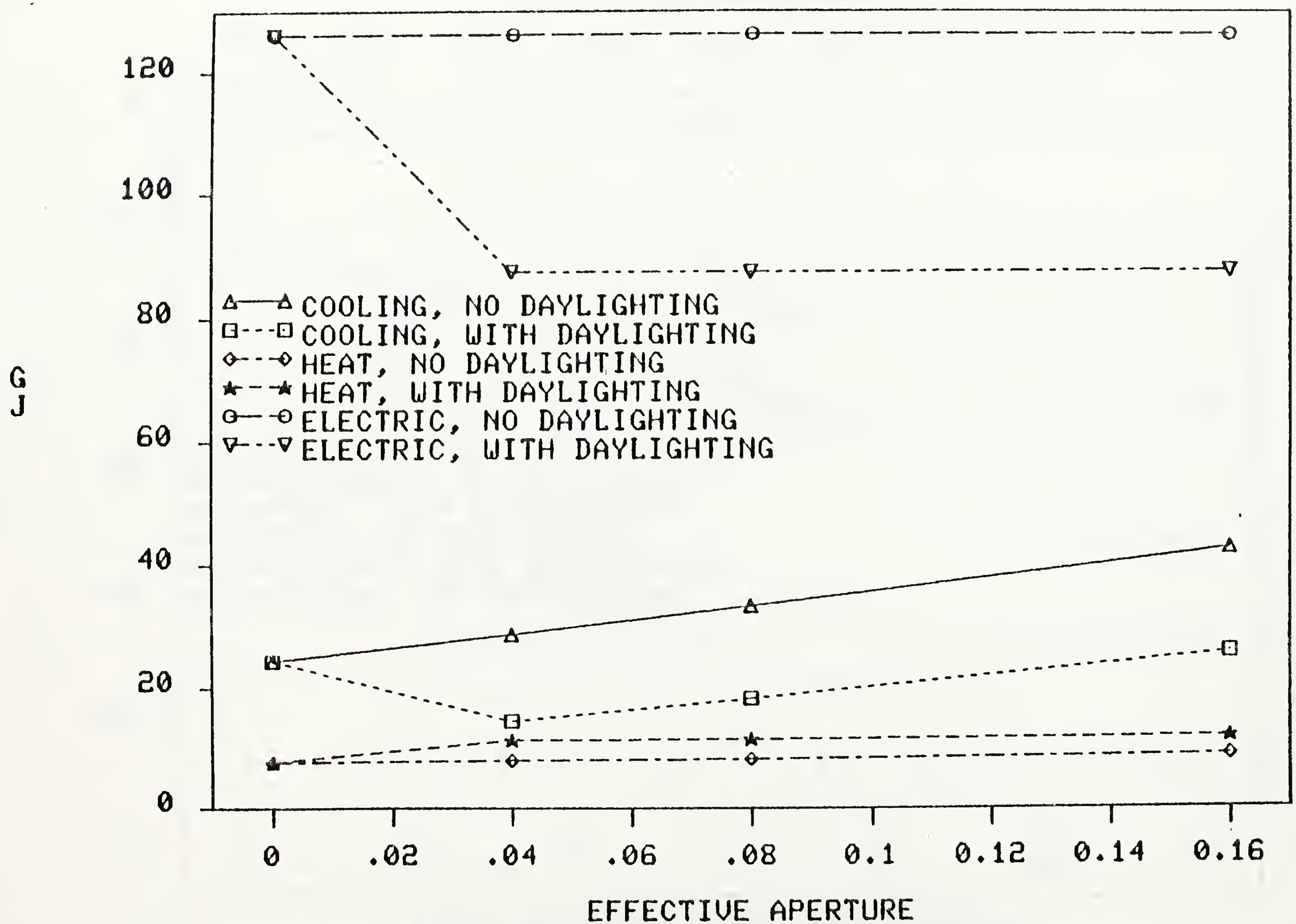


Figure 1[illegible]0. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego) SOUTH WINDOW, BRICK FREESTANDING

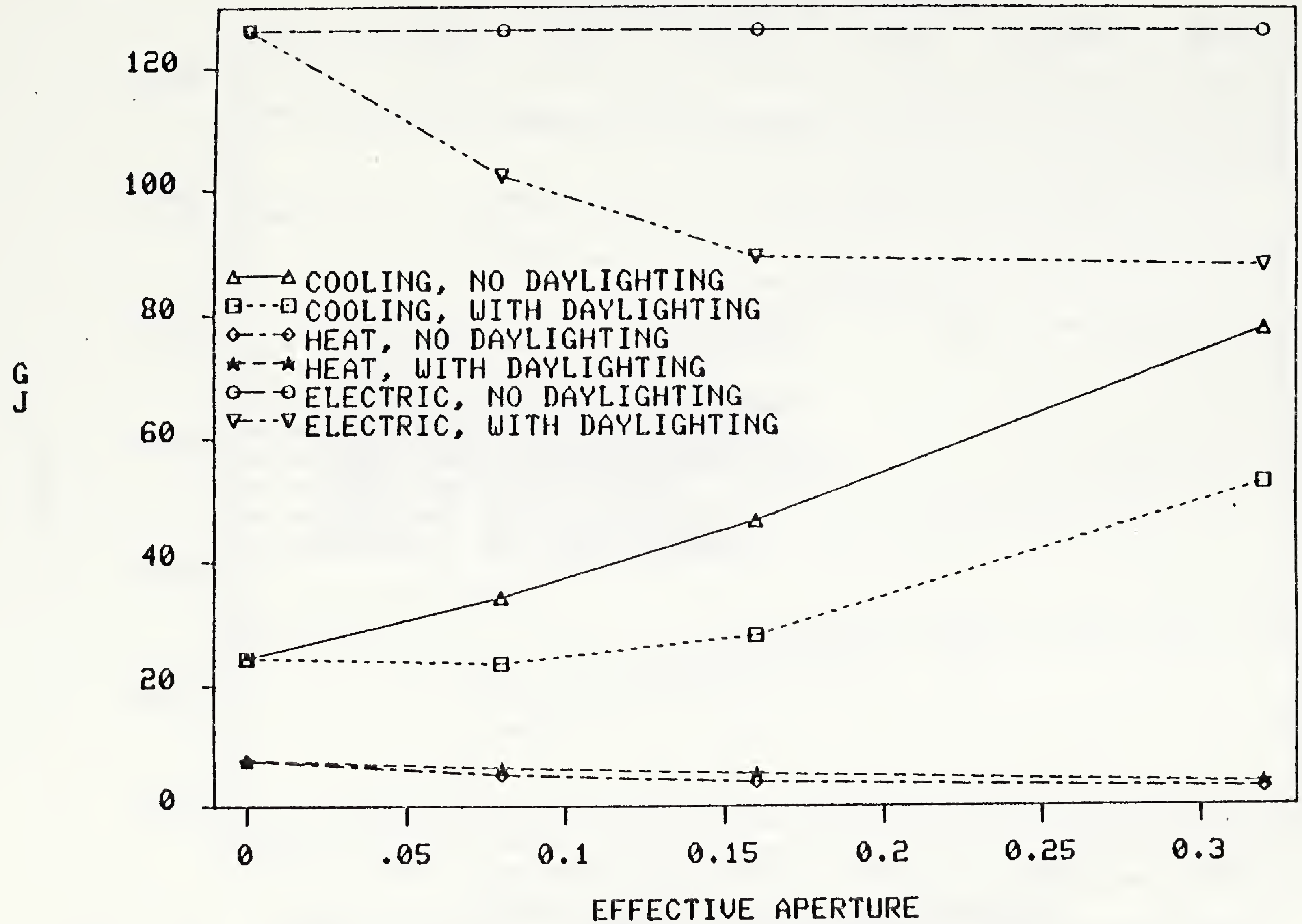


Figure 131. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
NORTH WINDOW, BRICK FREESTANDING

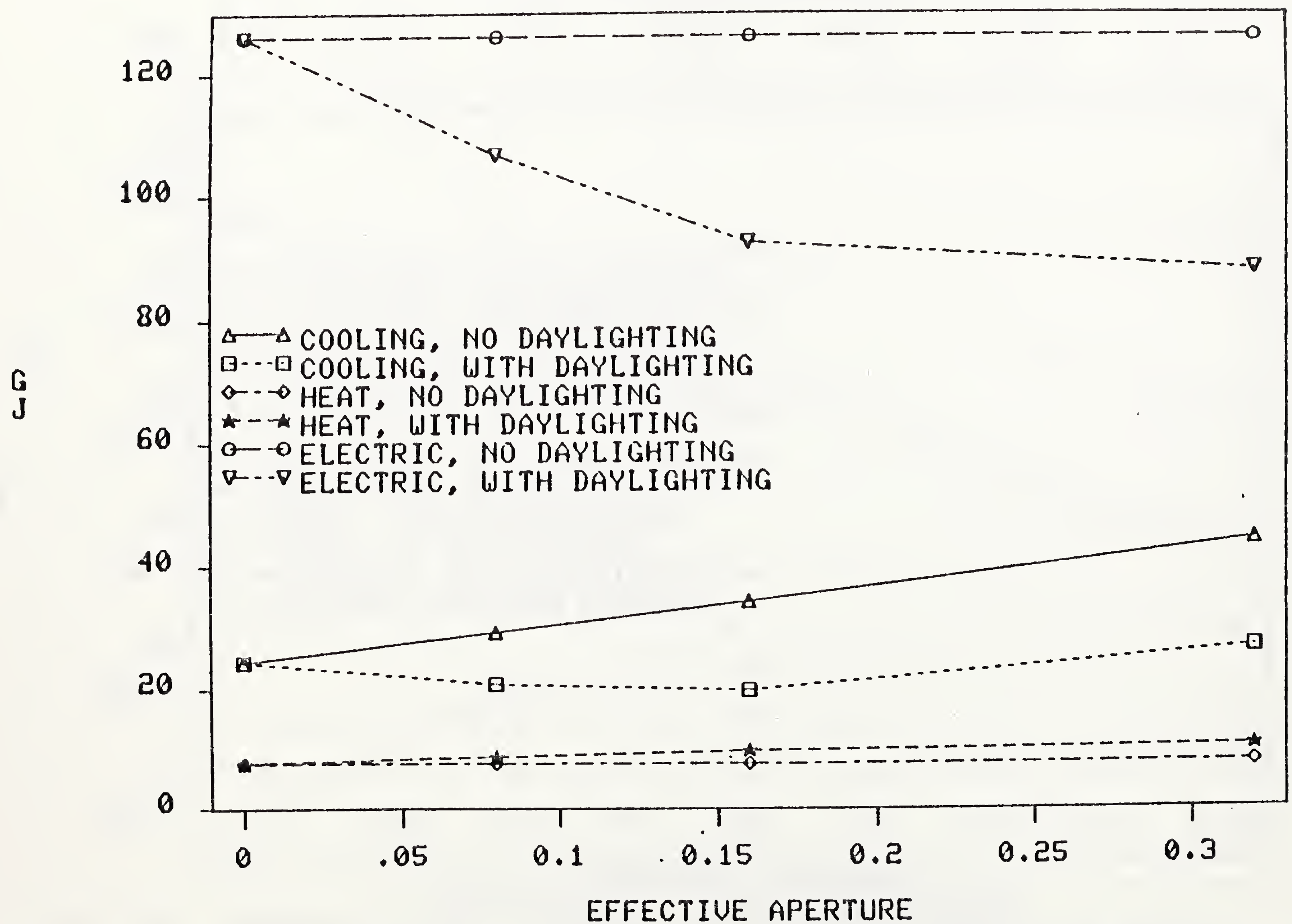


Figure 132. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego) SKYLIGHTS, BRICK ATTACHED

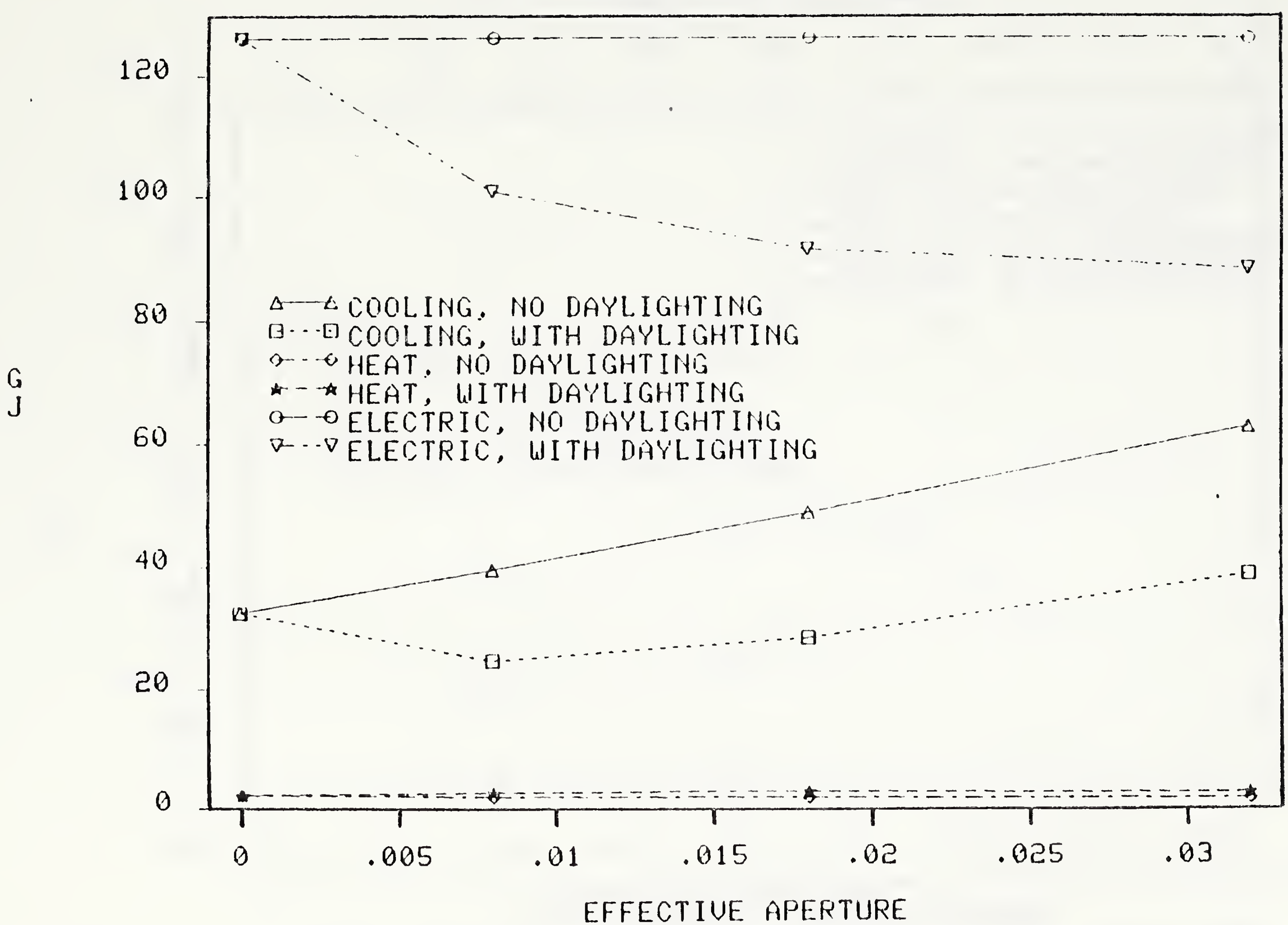


Figure 133. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego) SOUTH SAWTOOTH, BRICK ATTACHED

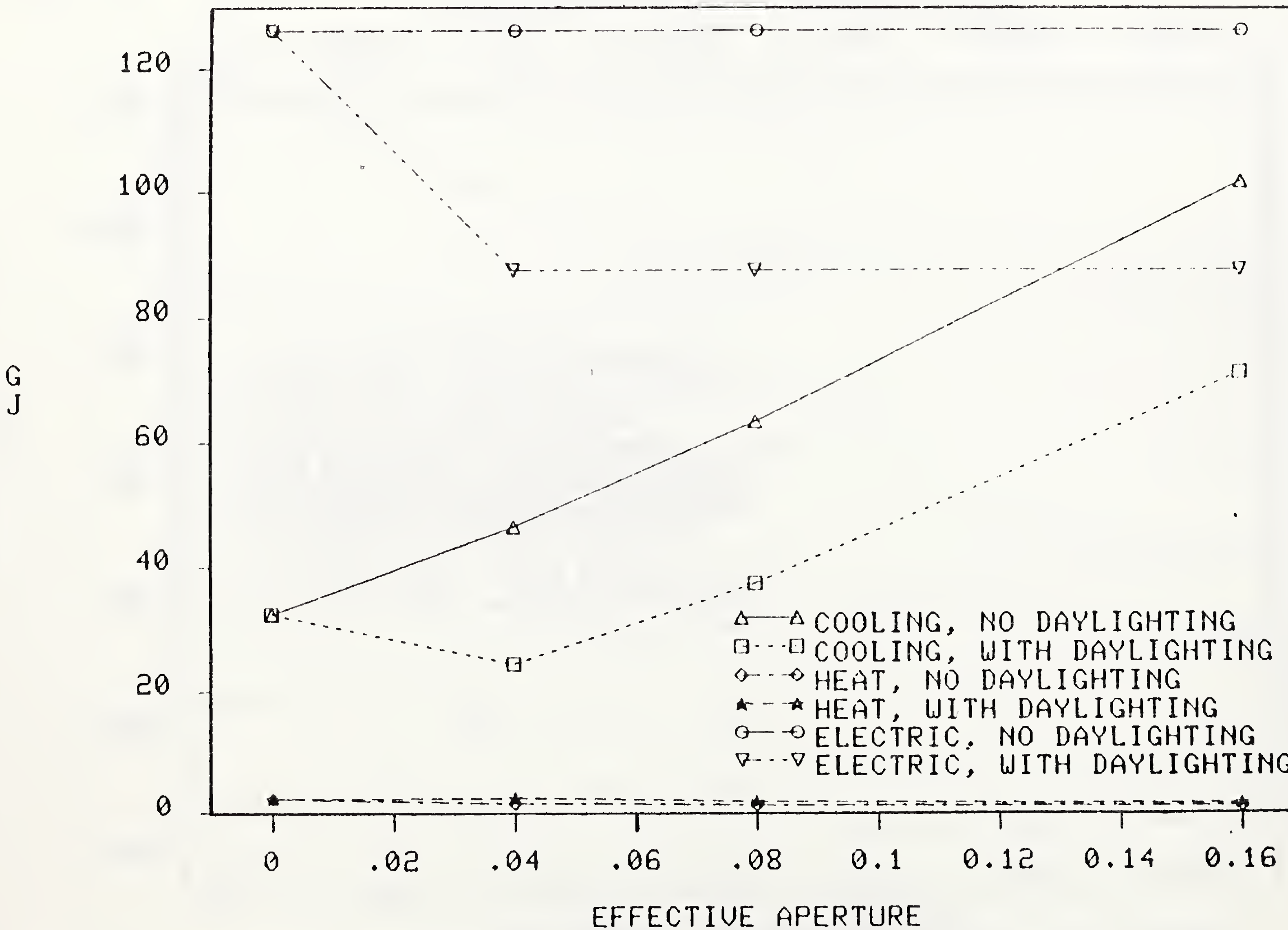


Figure 134. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
NORTH SAWTOOTH, BRICK ATTACHED

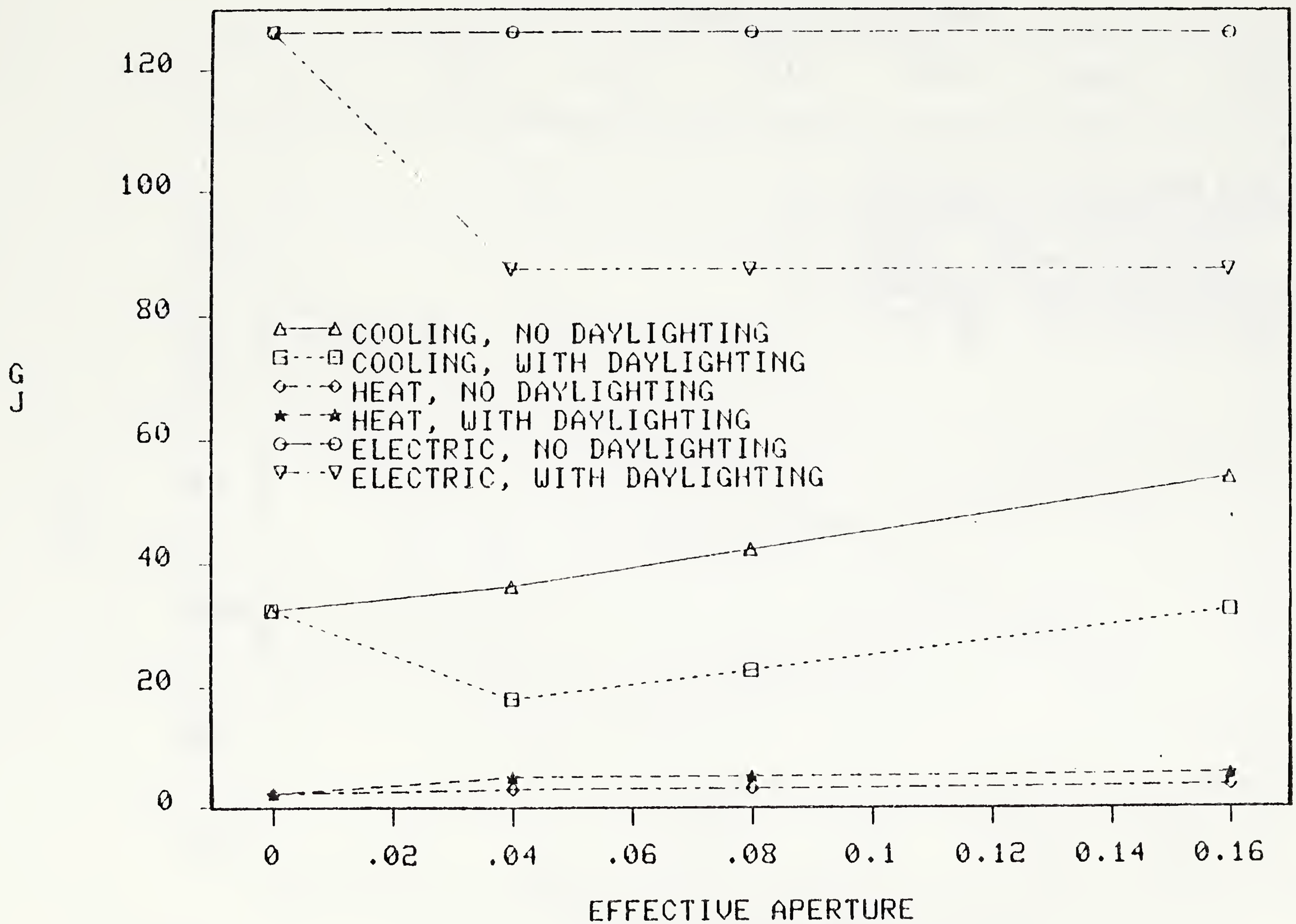


Figure 135. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego) SOUTH WINDOW, BRICK ATTACHED

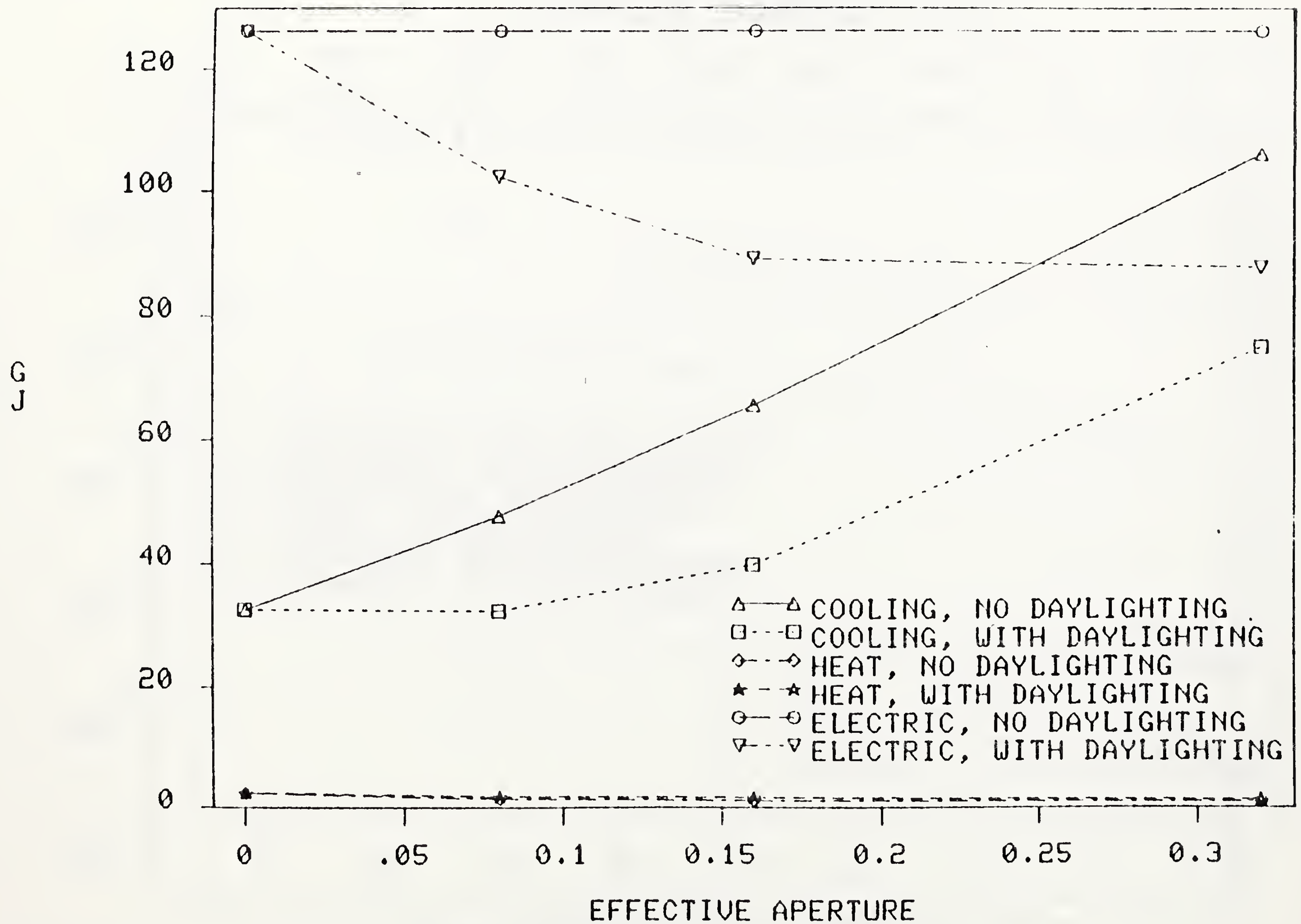


Figure 136. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
NORTH WINDOW, BRICK ATTACHED

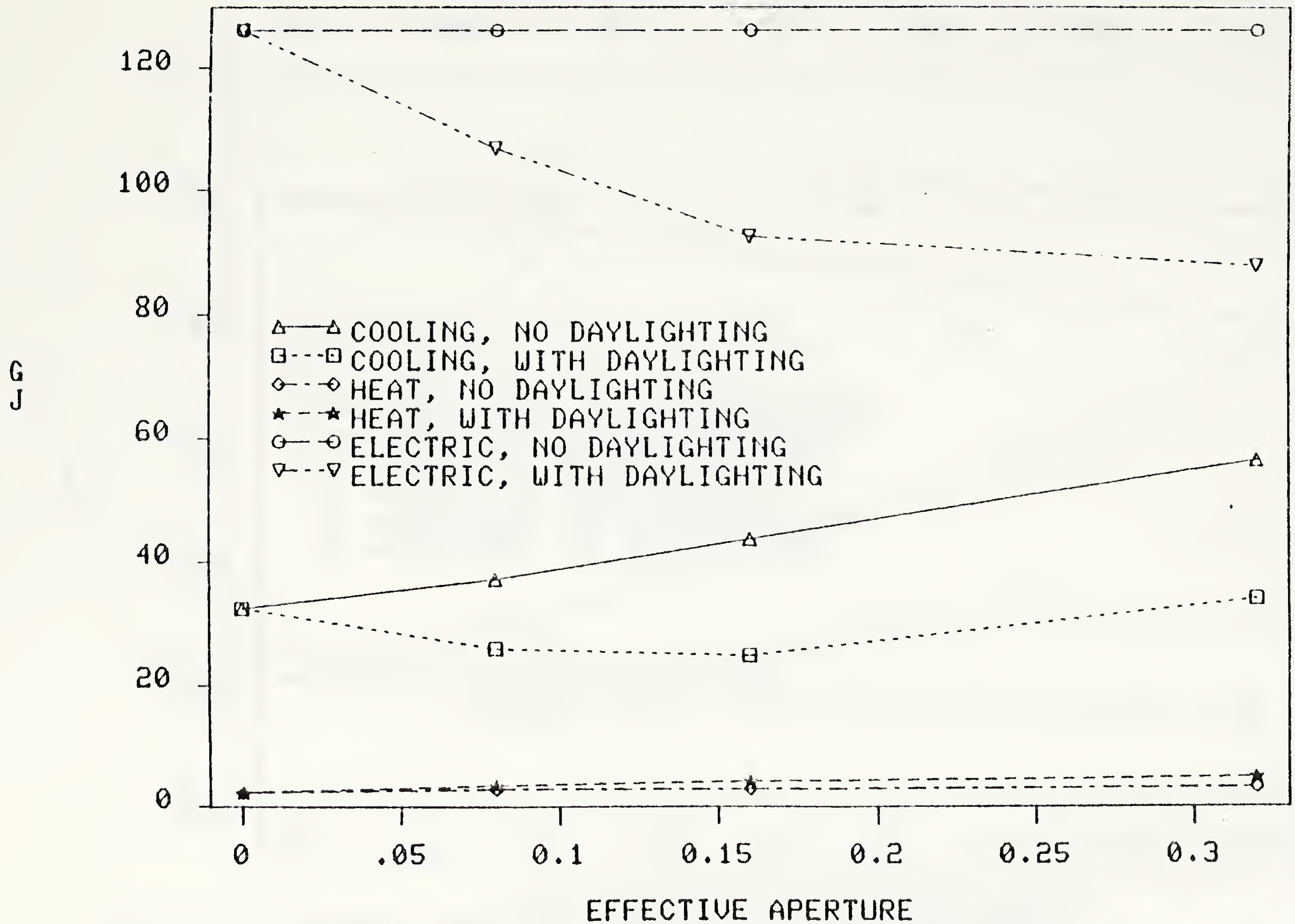


Figure 137. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
SKYLIGHTS, METAL FREESTANDING

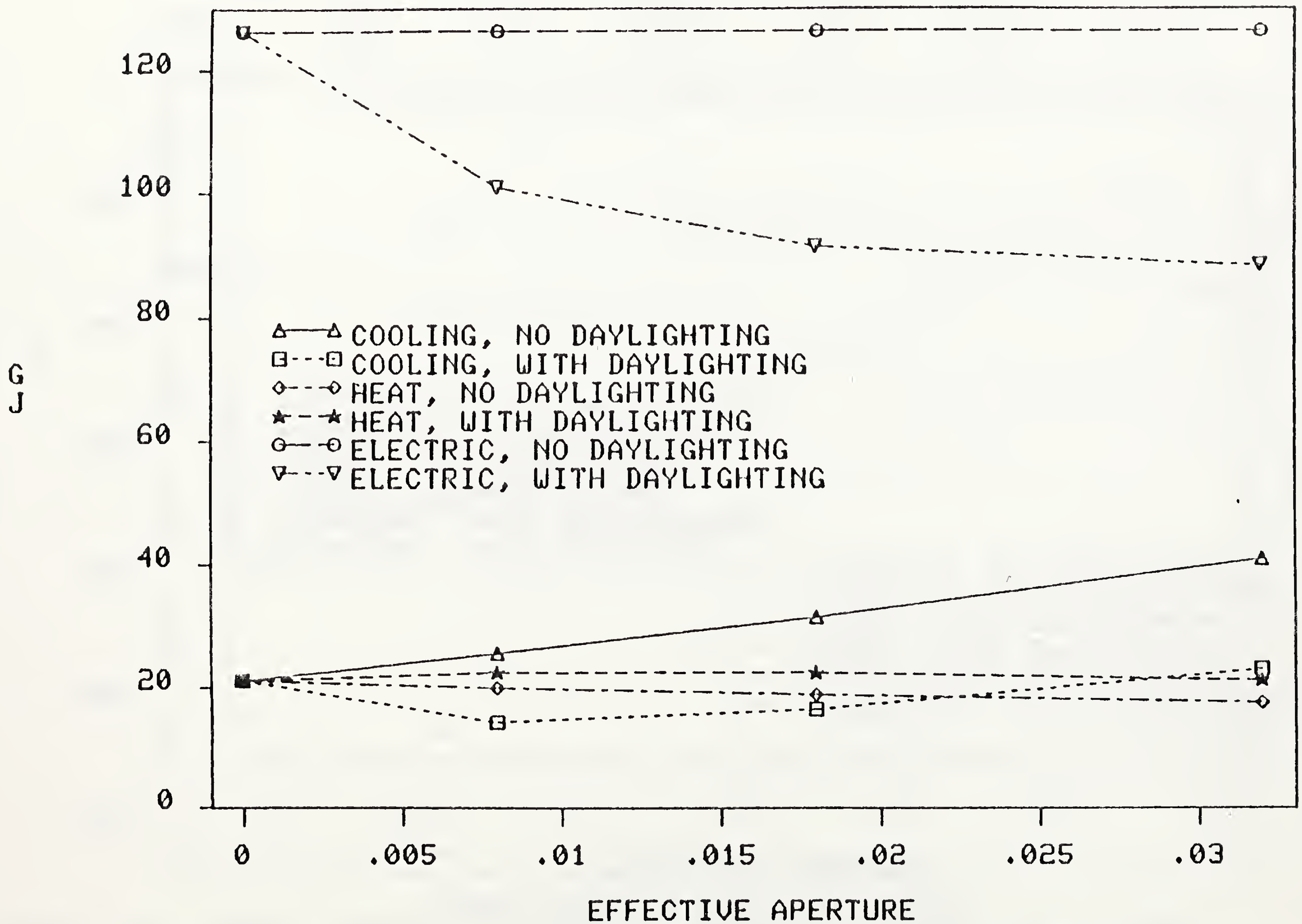


Figure 138. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
SOUTH SAWTOOTH, METAL FREESTANDING

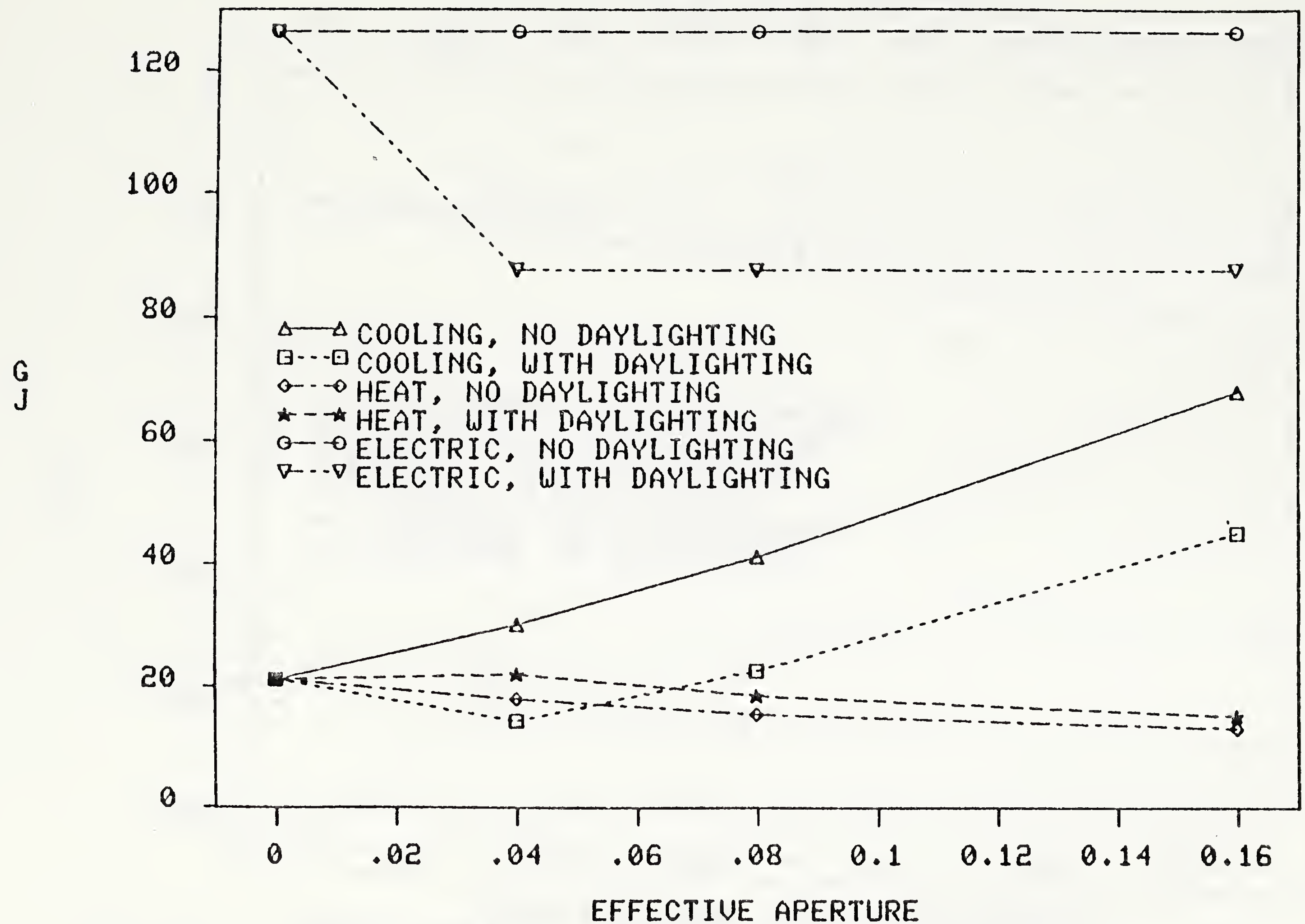


Figure 139. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
NORTH SAWTOOTH, METAL FREESTANDING

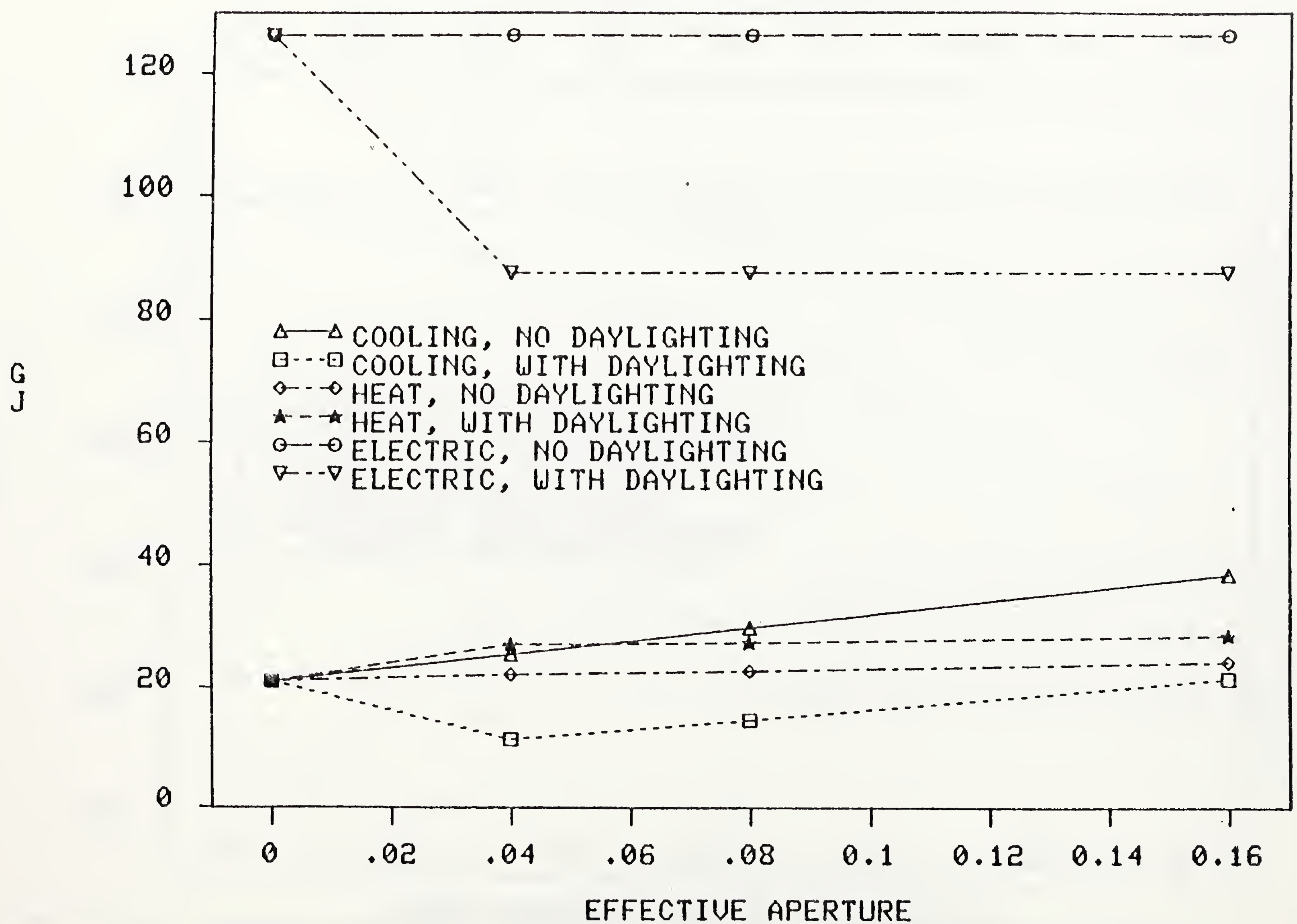


Figure 140. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
SOUTH WINDOW, METAL FREESTANDING

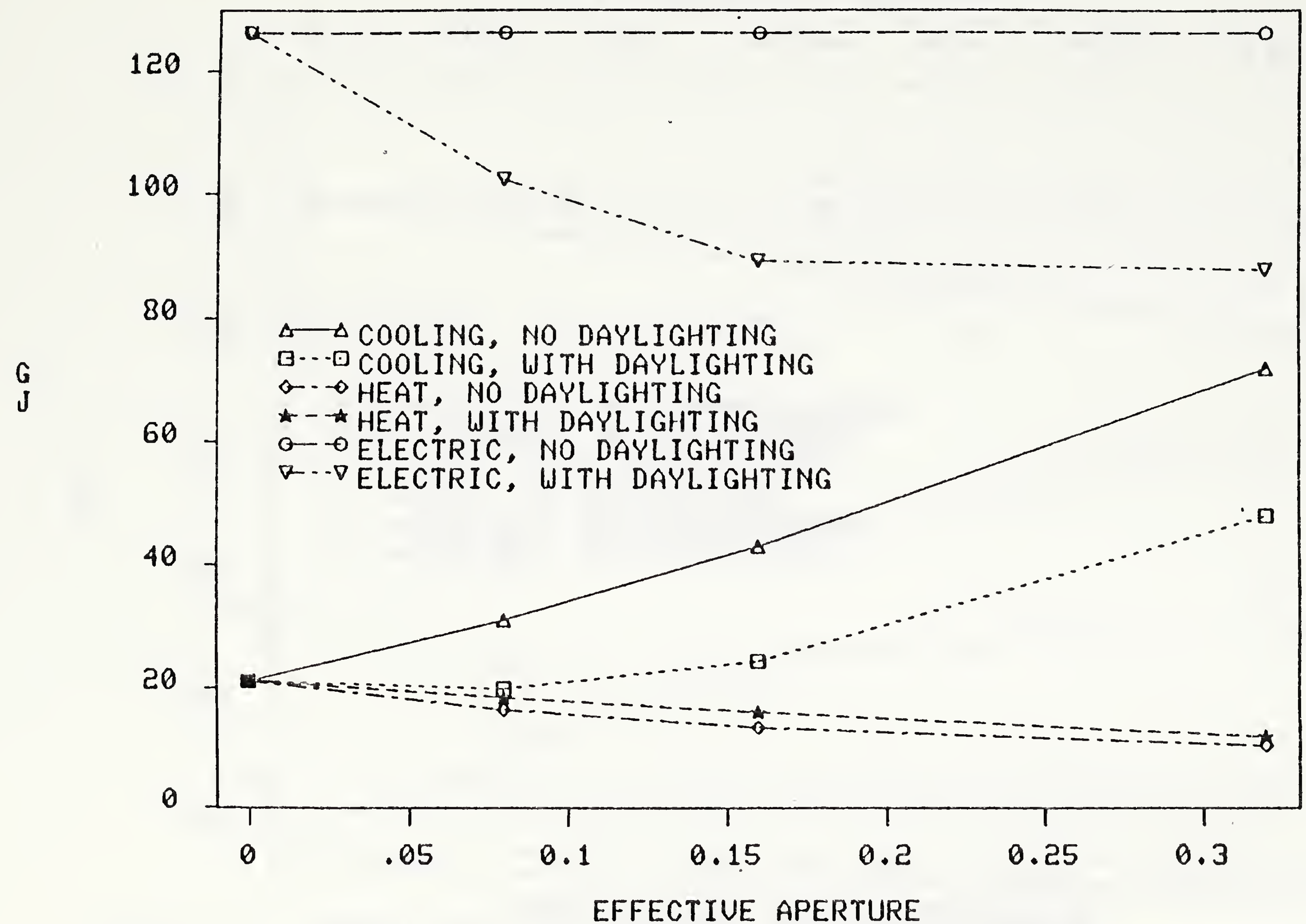


Figure 141. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego) NORTH WINDOW, METAL FREESTANDING

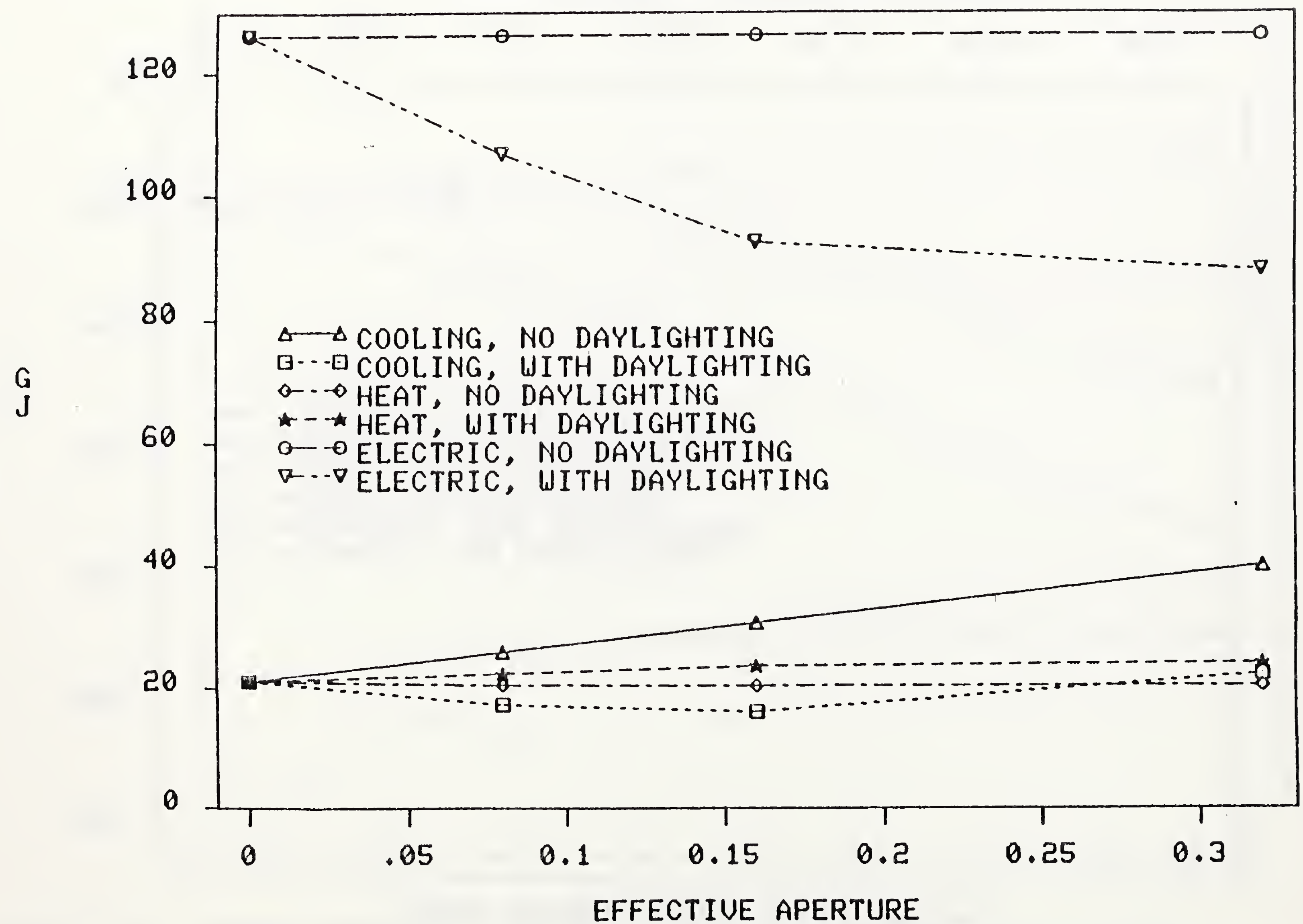


Figure 142. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
SKYLIGHTS, METAL ATTACHED

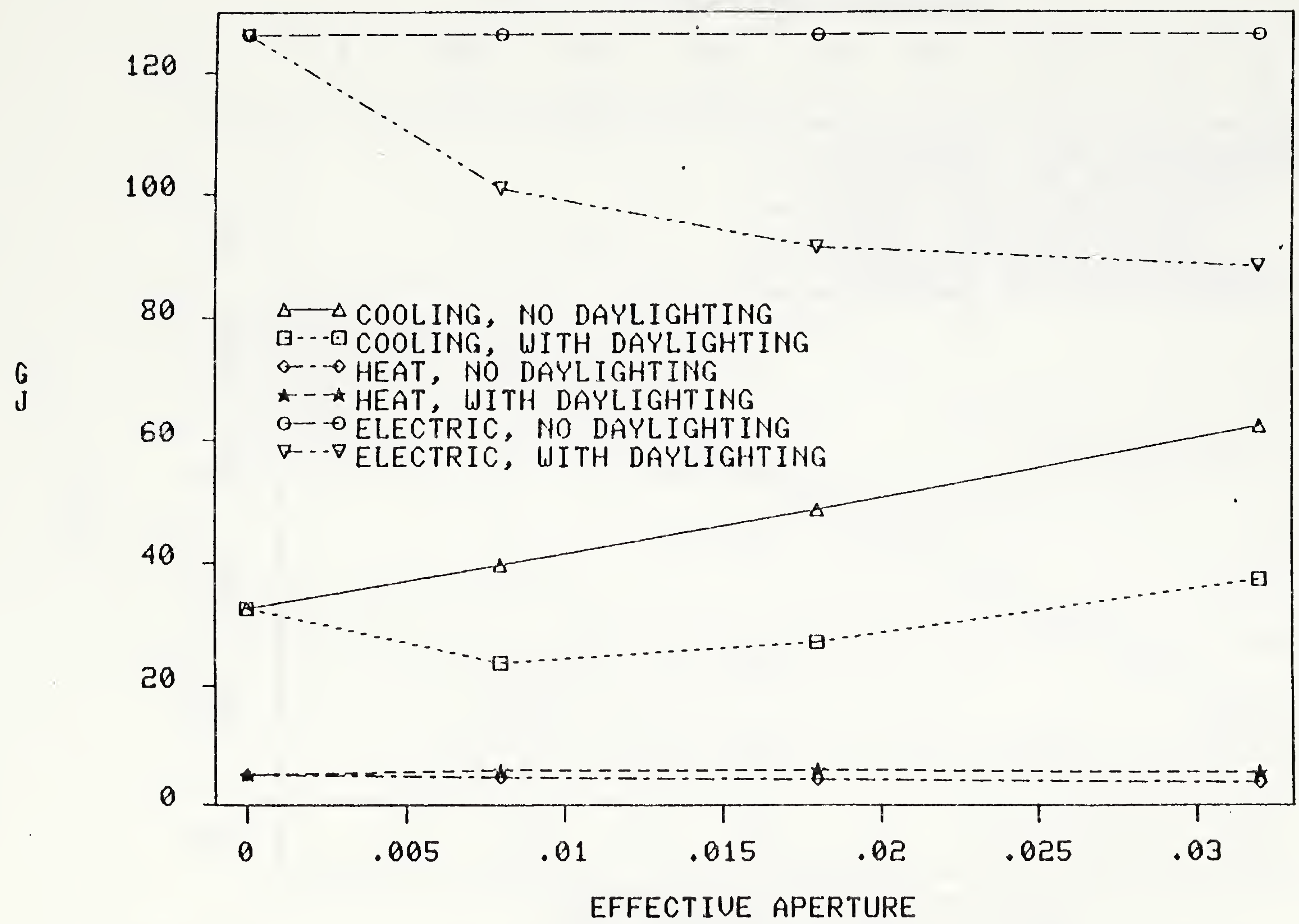


Figure 143. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego) SOUTH SAWTOOTH, METAL ATTACHED

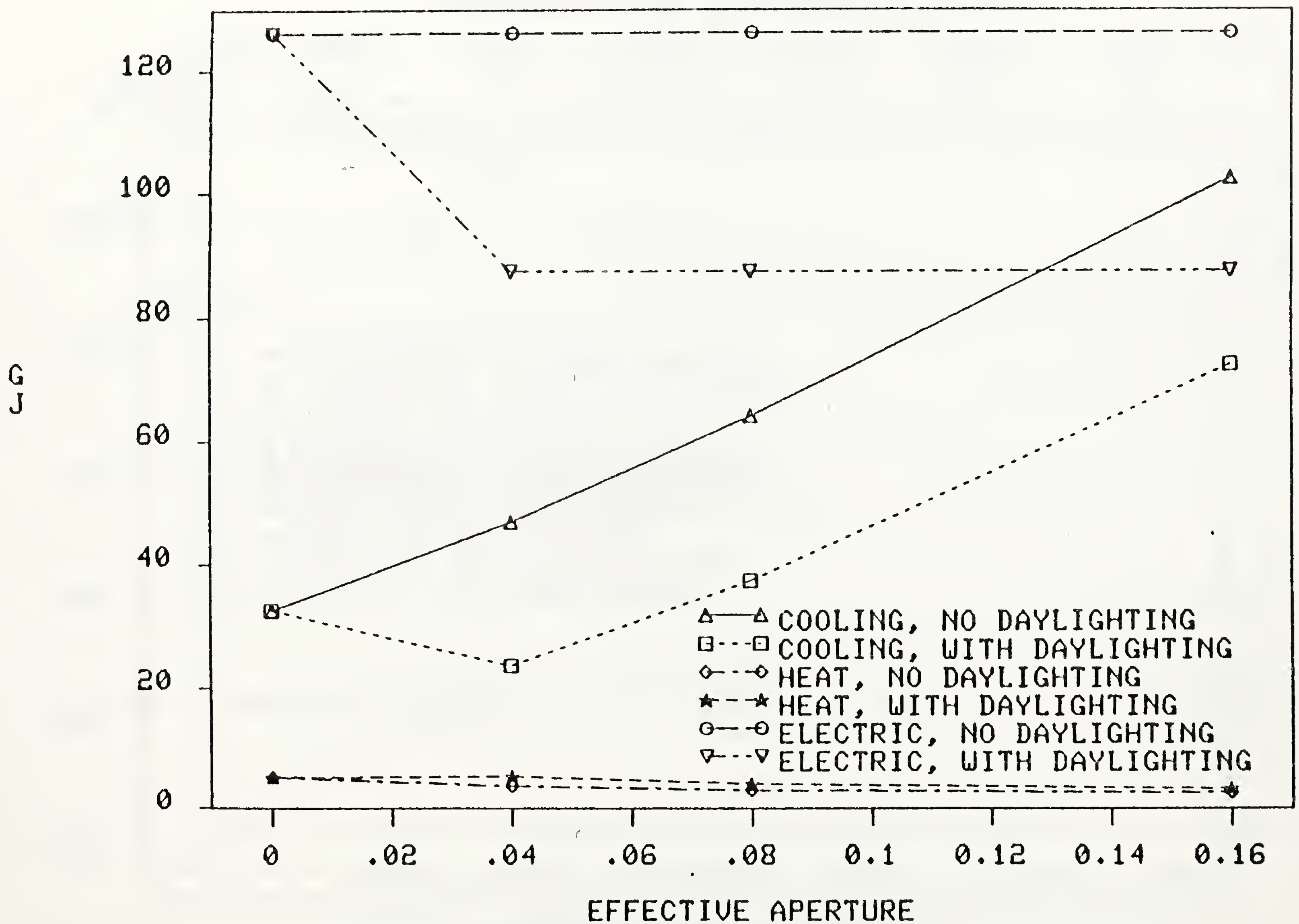


Figure 144. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
NORTH SAWTOOTH, METAL ATTACHED

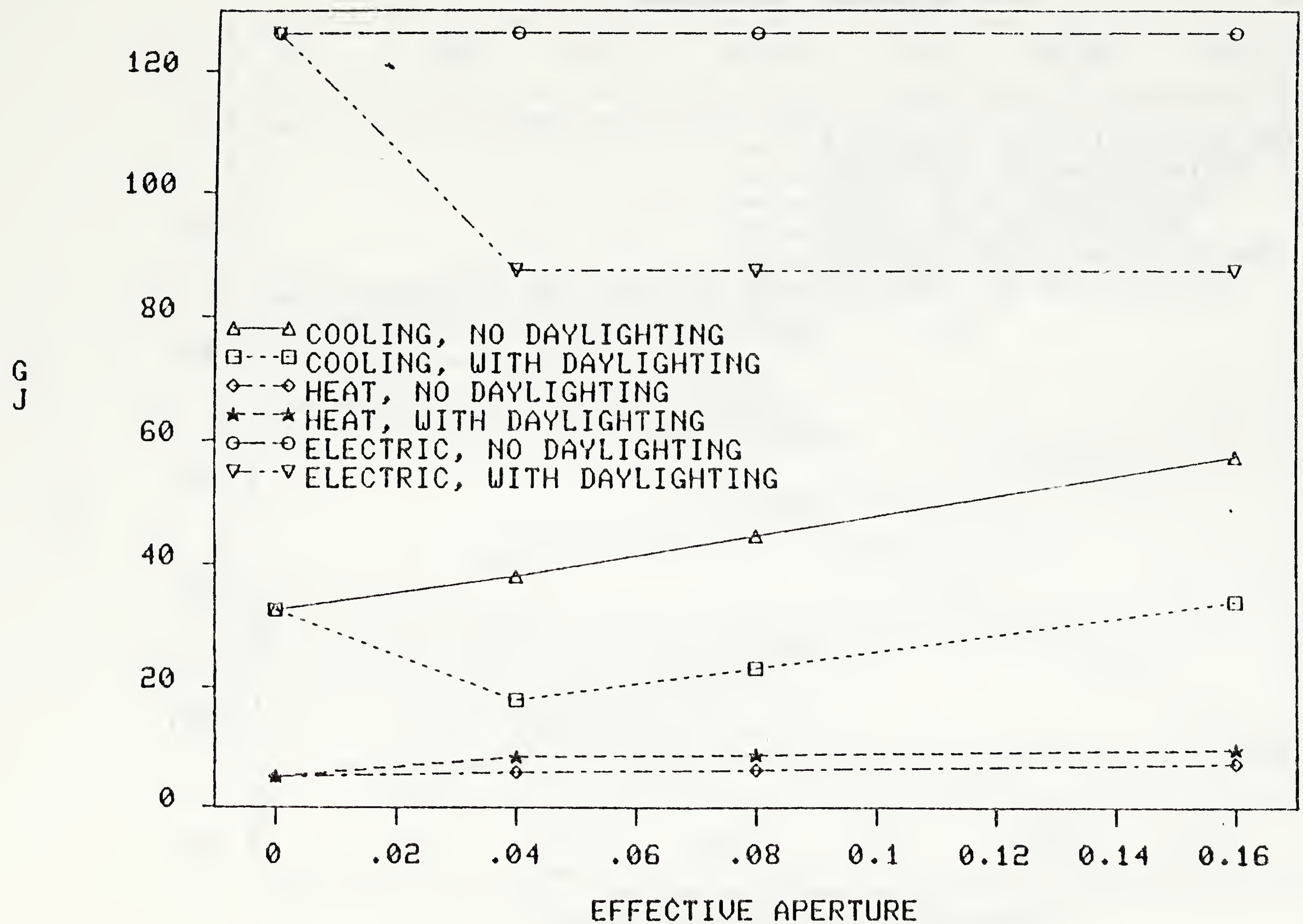


Figure 145. ANNUAL COOLING, HEATING AND ELECTRIC LOADS (San Diego) SOUTH WINDOW, METAL ATTACHED

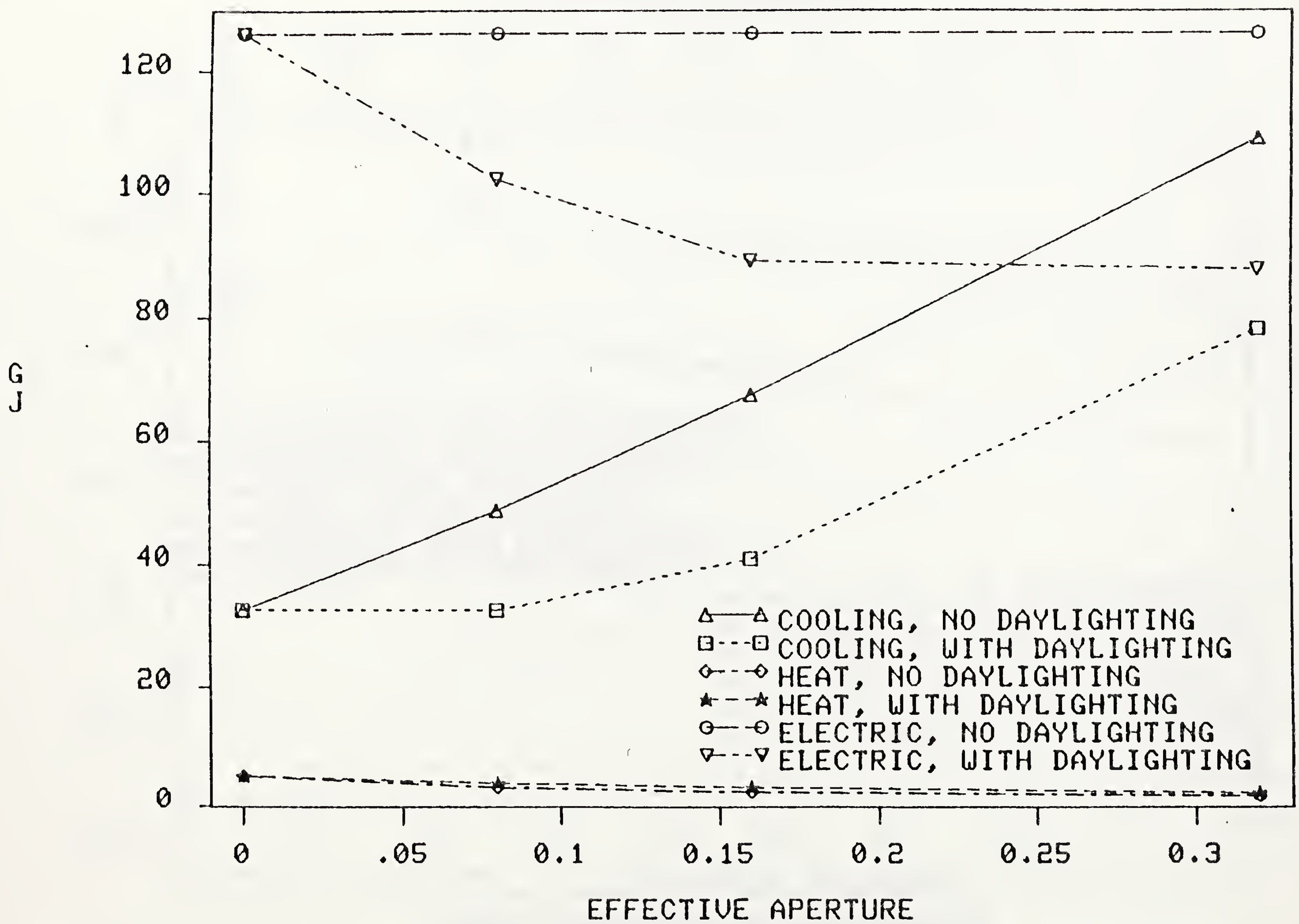


Figure 146. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (San Diego)
NORTH WINDOW, METAL ATTACHED

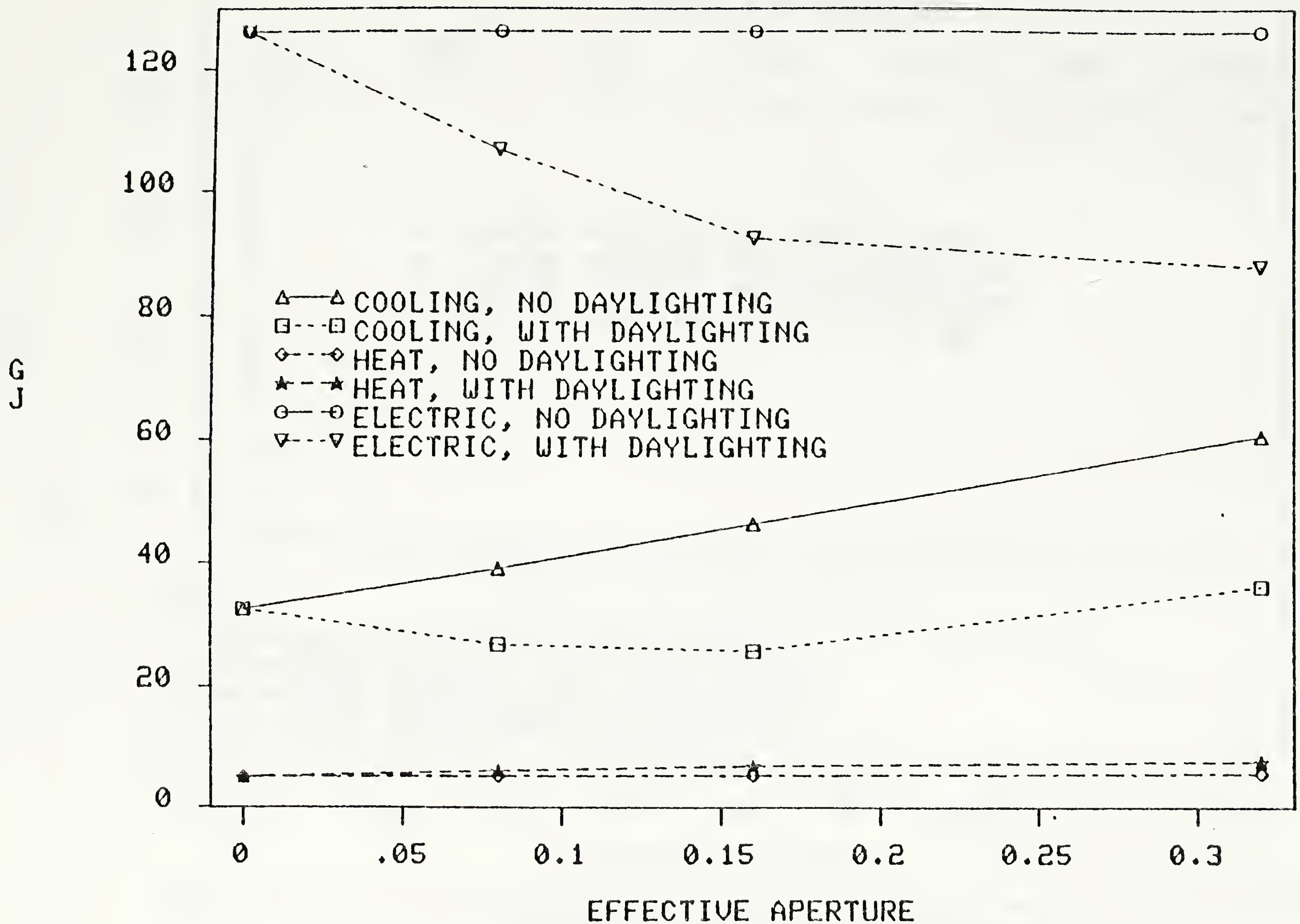


Figure 147. PEAK HEATING AND COOLING LOADS (San Diego)
SKYLIGHTS, BRICK FREESTANDING

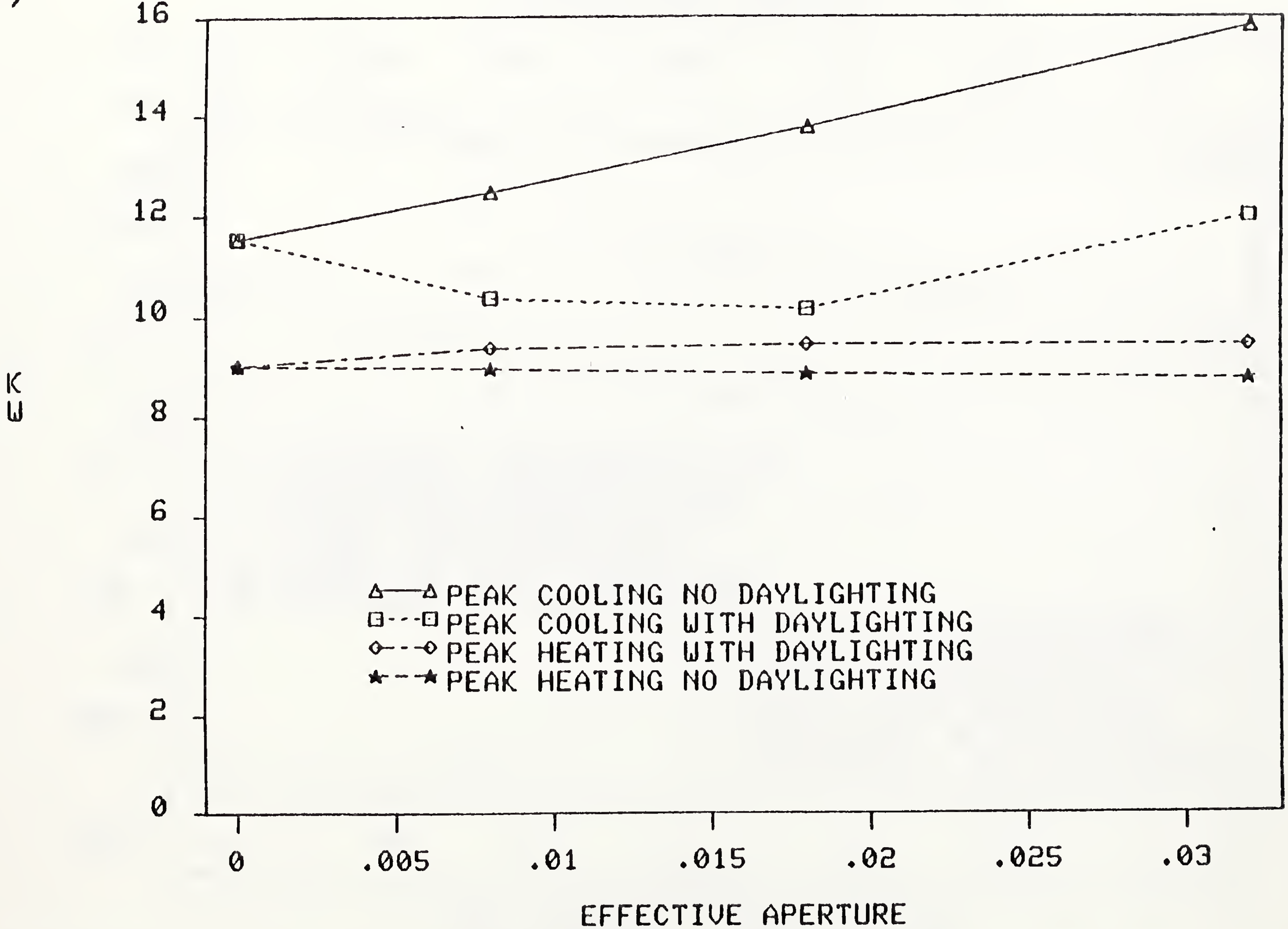


Figure 118. PEAK HEATING AND COOLING LOADS (San Diego)
SOUTH SAWTOOTH, BRICK FREESTANDING

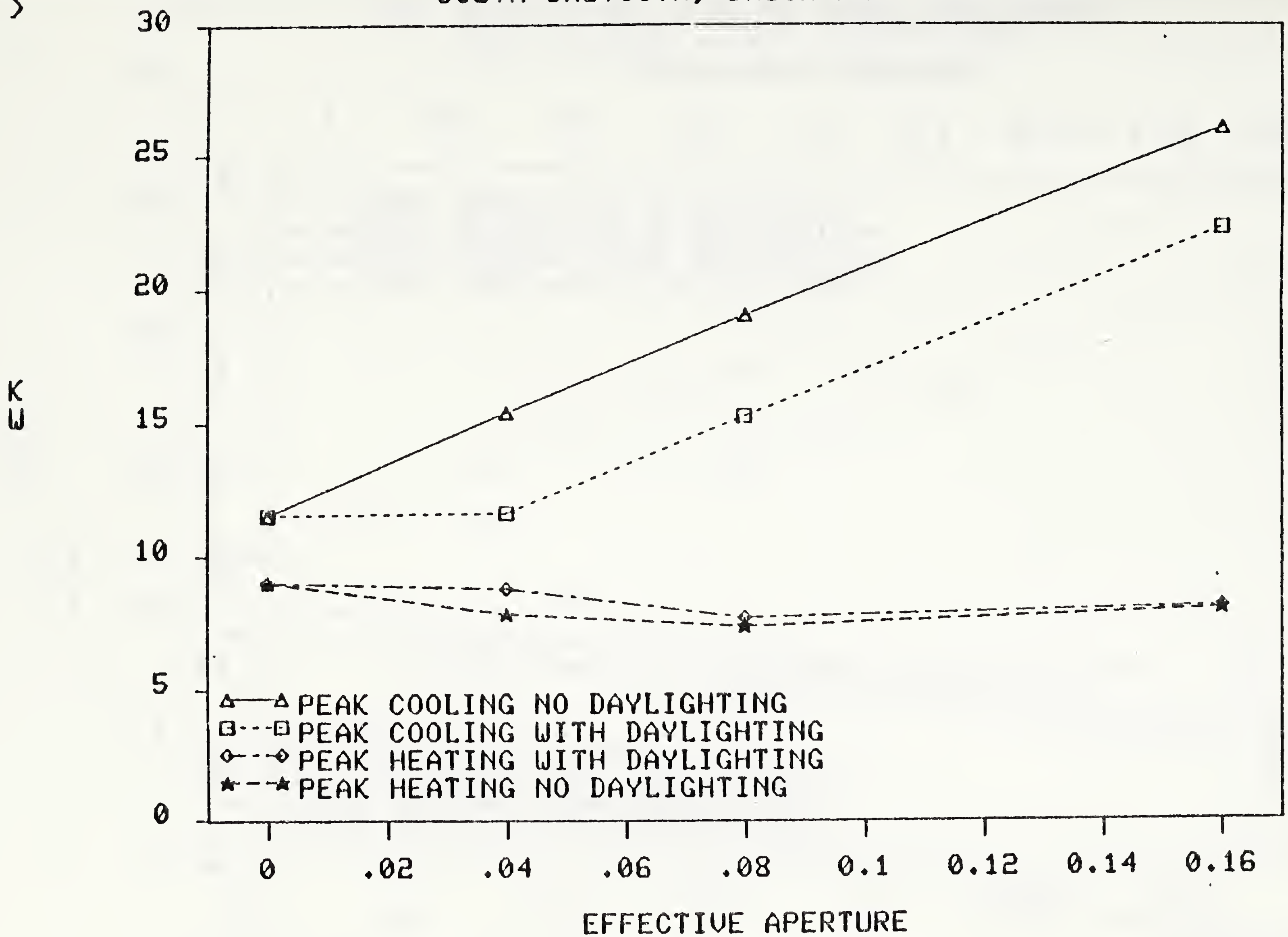


Figure 119. PEAK HEATING AND COOLING LOADS (San Diego) NORTH SAWTOOTH, BRICK FREESTANDING

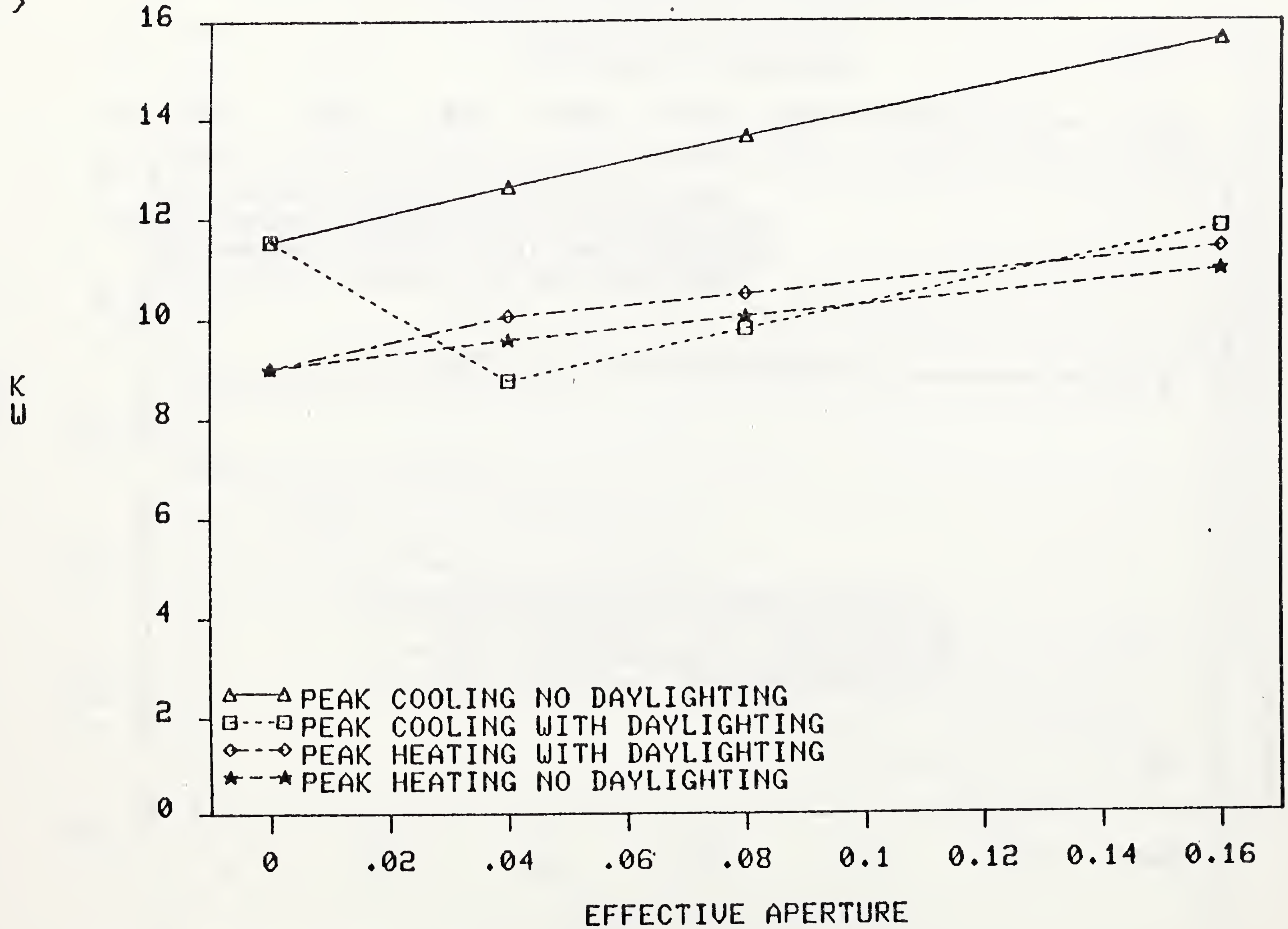


Figure 150. PEAK HEATING AND COOLING LOADS (San Diego)
SOUTH WINDOW, BRICK FREESTANDING

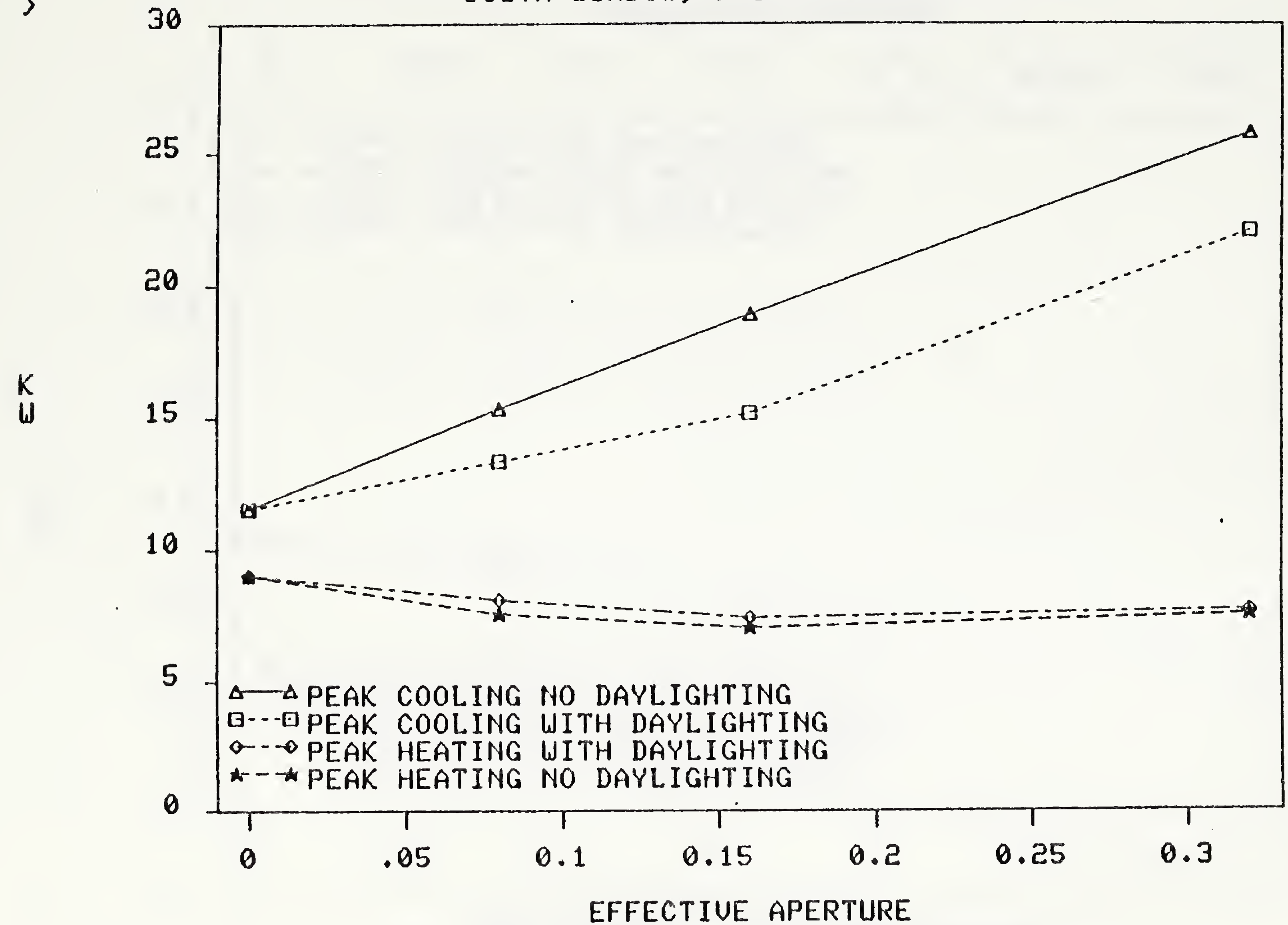


Figure 151. PEAK HEATING AND COOLING LOADS (San Diego)
NORTH WINDOW, BRICK FREESTANDING

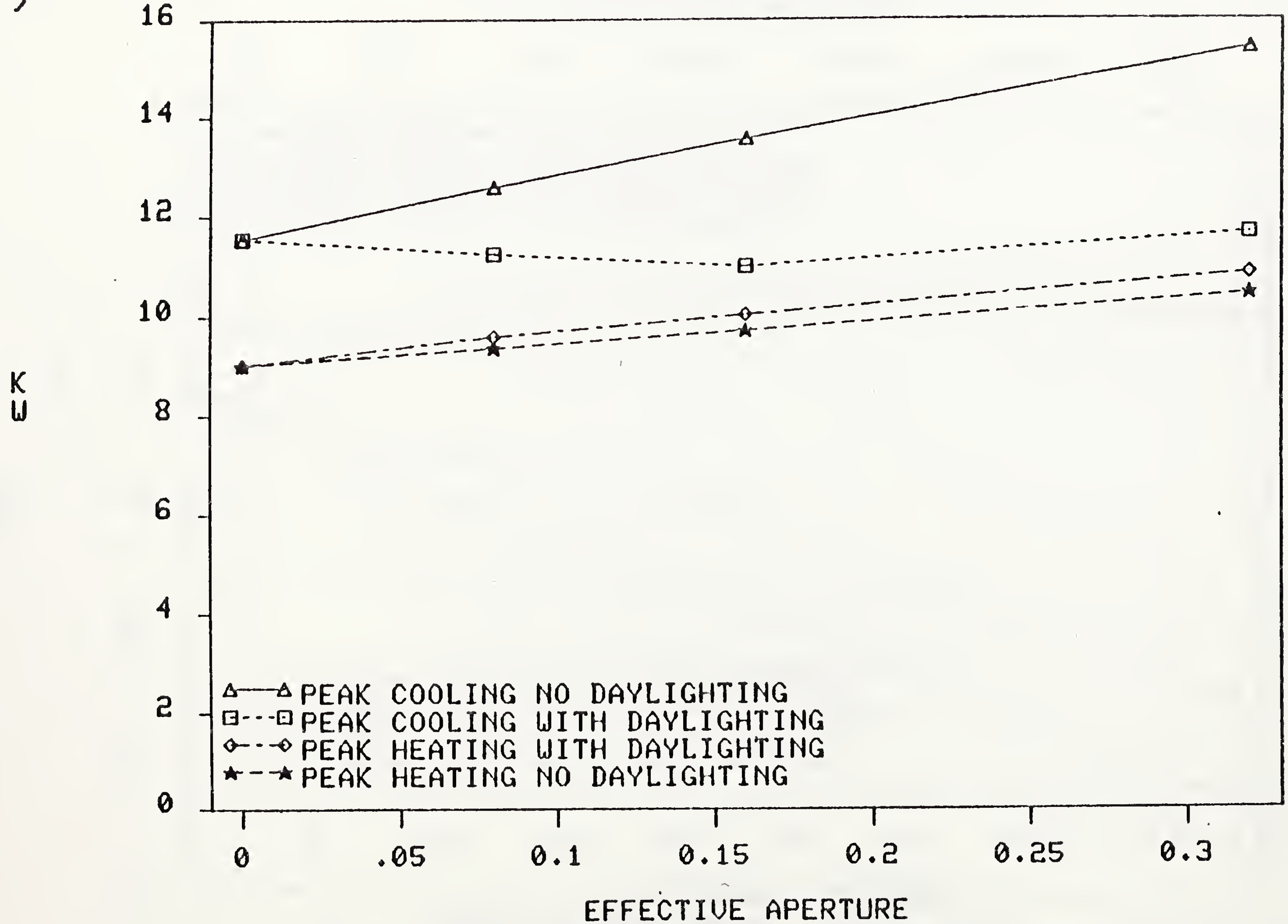


Figure 152. PEAK HEATING AND COOLING LOADS (San Diego)
SKYLIGHTS, BRICK ATTACHED

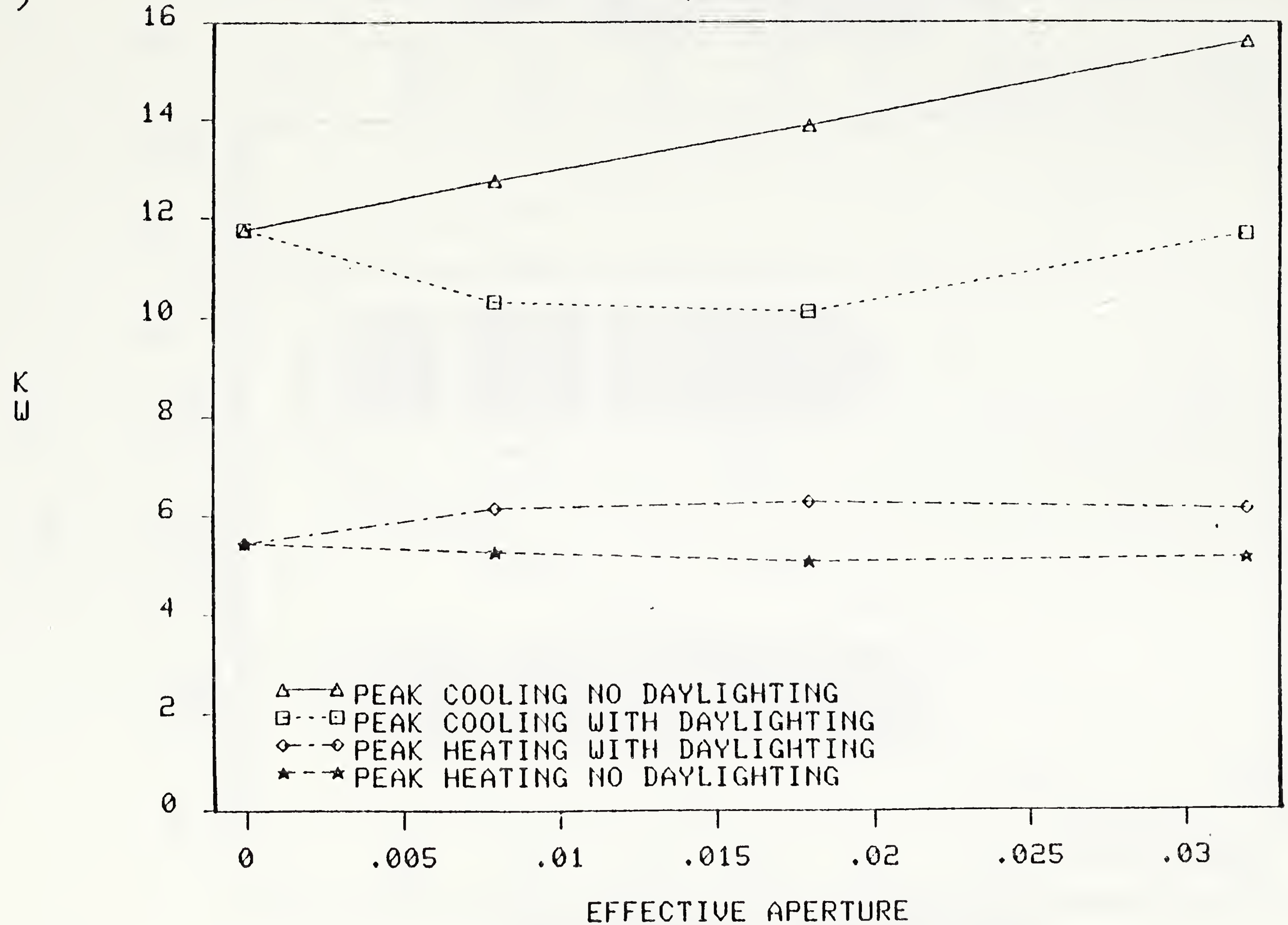


Figure 153. PEAK HEATING AND COOLING LOADS (San Diego)
SOUTH SAWTOOTH, BRICK ATTACHED

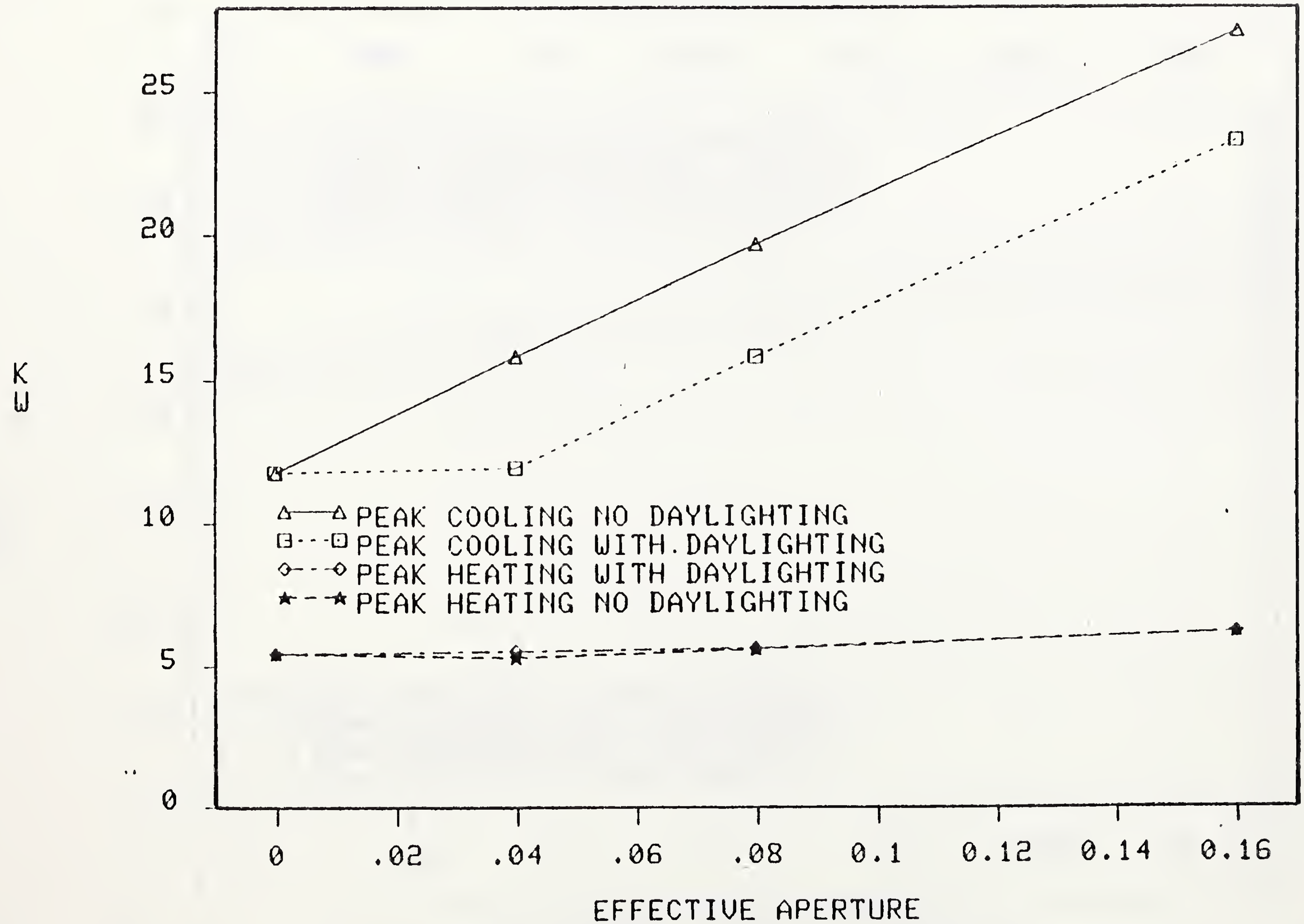


Figure 154. PEAK HEATING AND COOLING LOADS (San Diego)
NORTH SAWTOOTH, BRICK ATTACHED

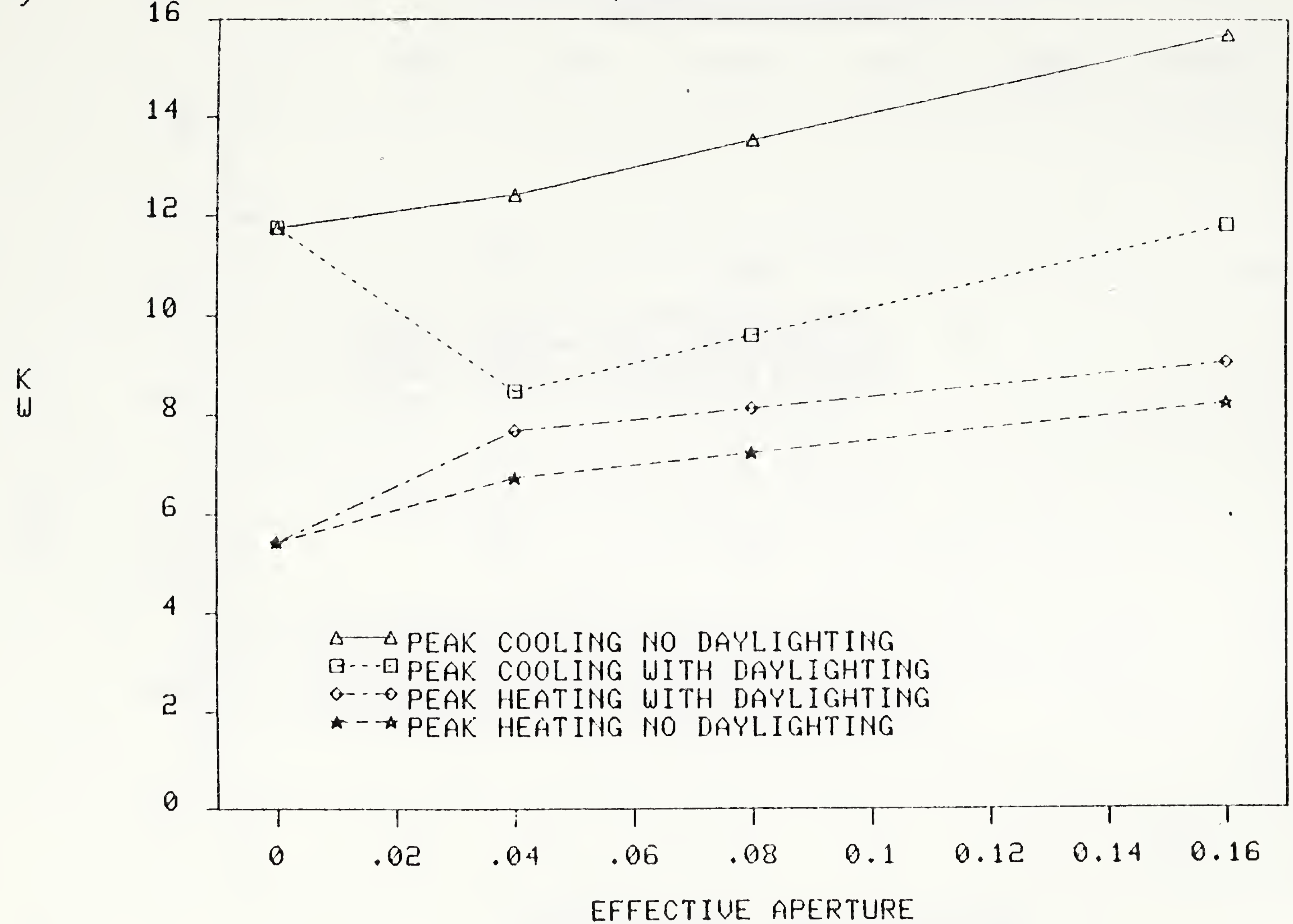


Figure 155. PEAK HEATING AND COOLING LOADS (San Diego)
SOUTH WINDOW, BRICK ATTACHED

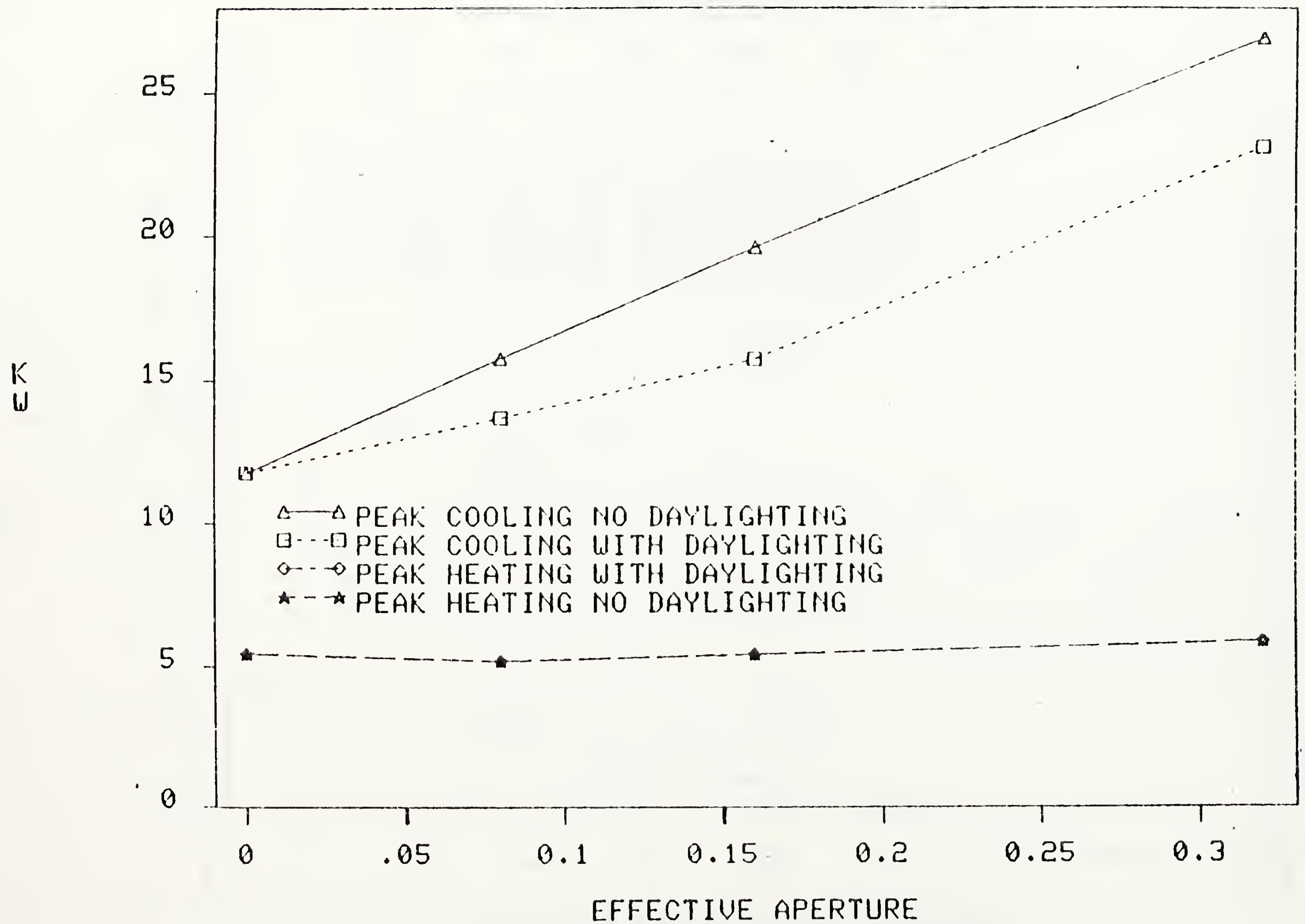


Figure 15.6. PEAK HEATING AND COOLING LOADS (San Diego)
NORTH WINDOW, BRICK ATTACHED

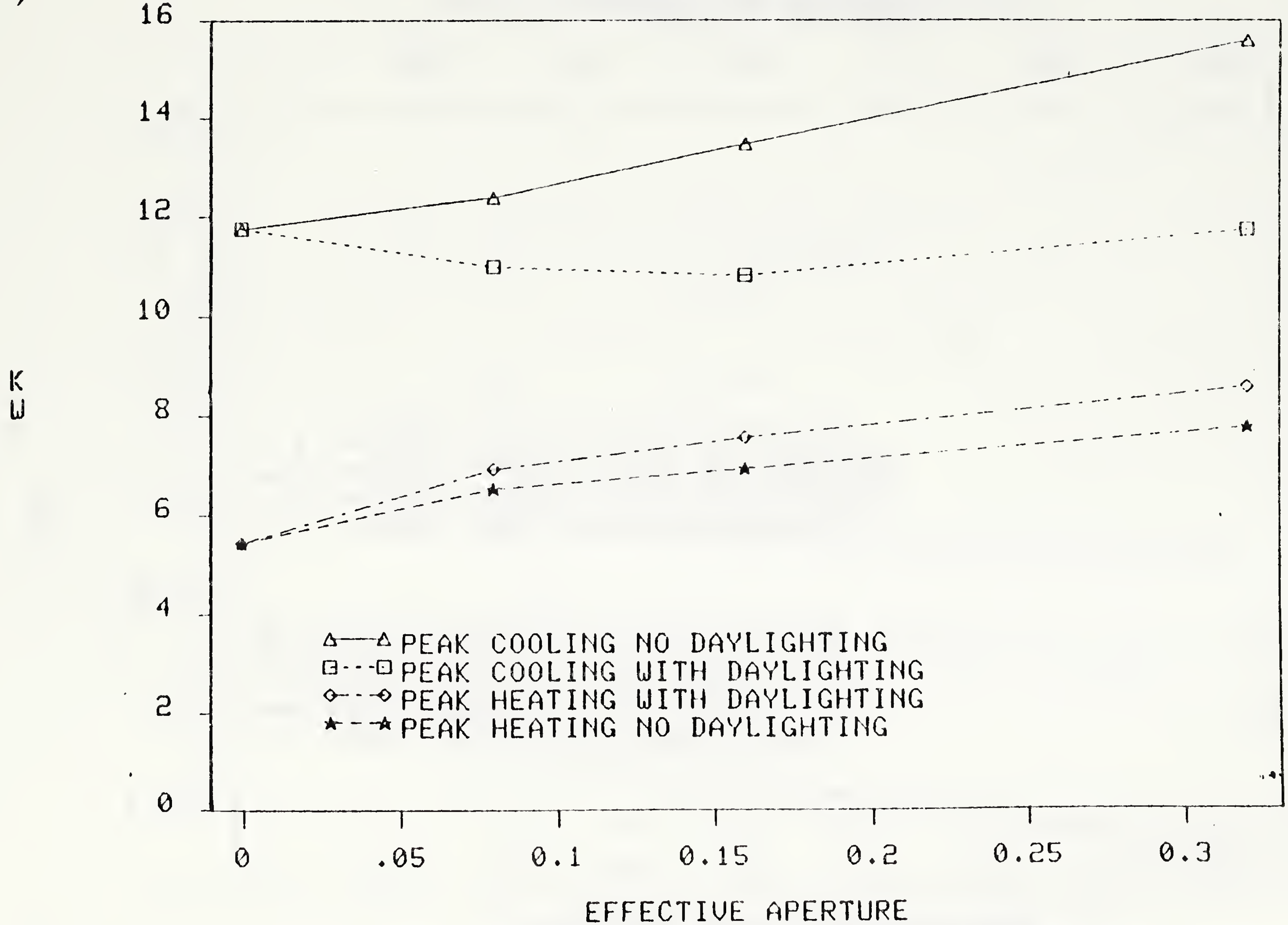


Figure 157. PEAK HEATING AND COOLING LOADS (San Diego)
SKYLIGHTS, METAL FREESTANDING

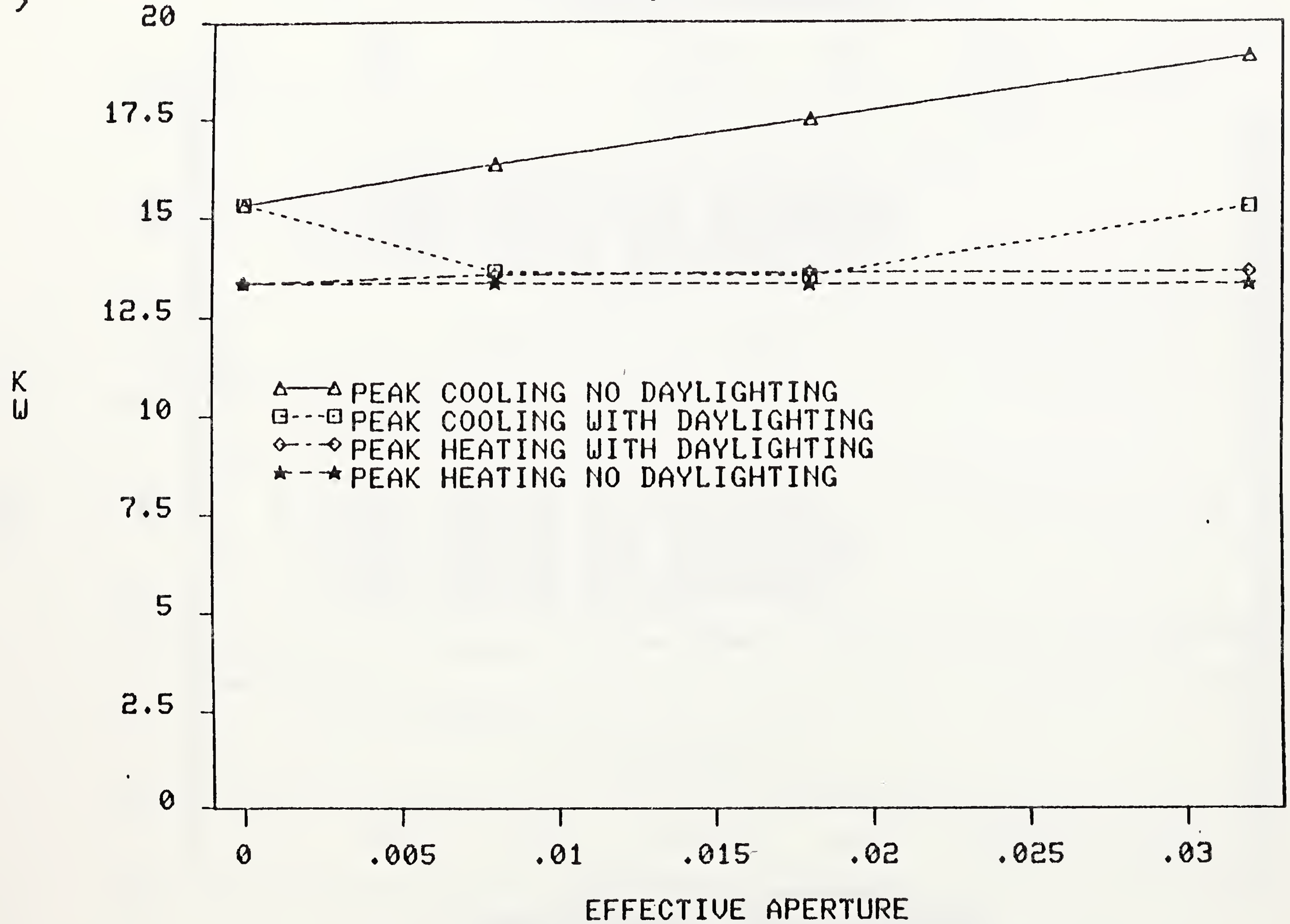


Figure 158. PEAK HEATING AND COOLING LOADS (San Diego)
SOUTH SAWTOOTH, METAL FREESTANDING

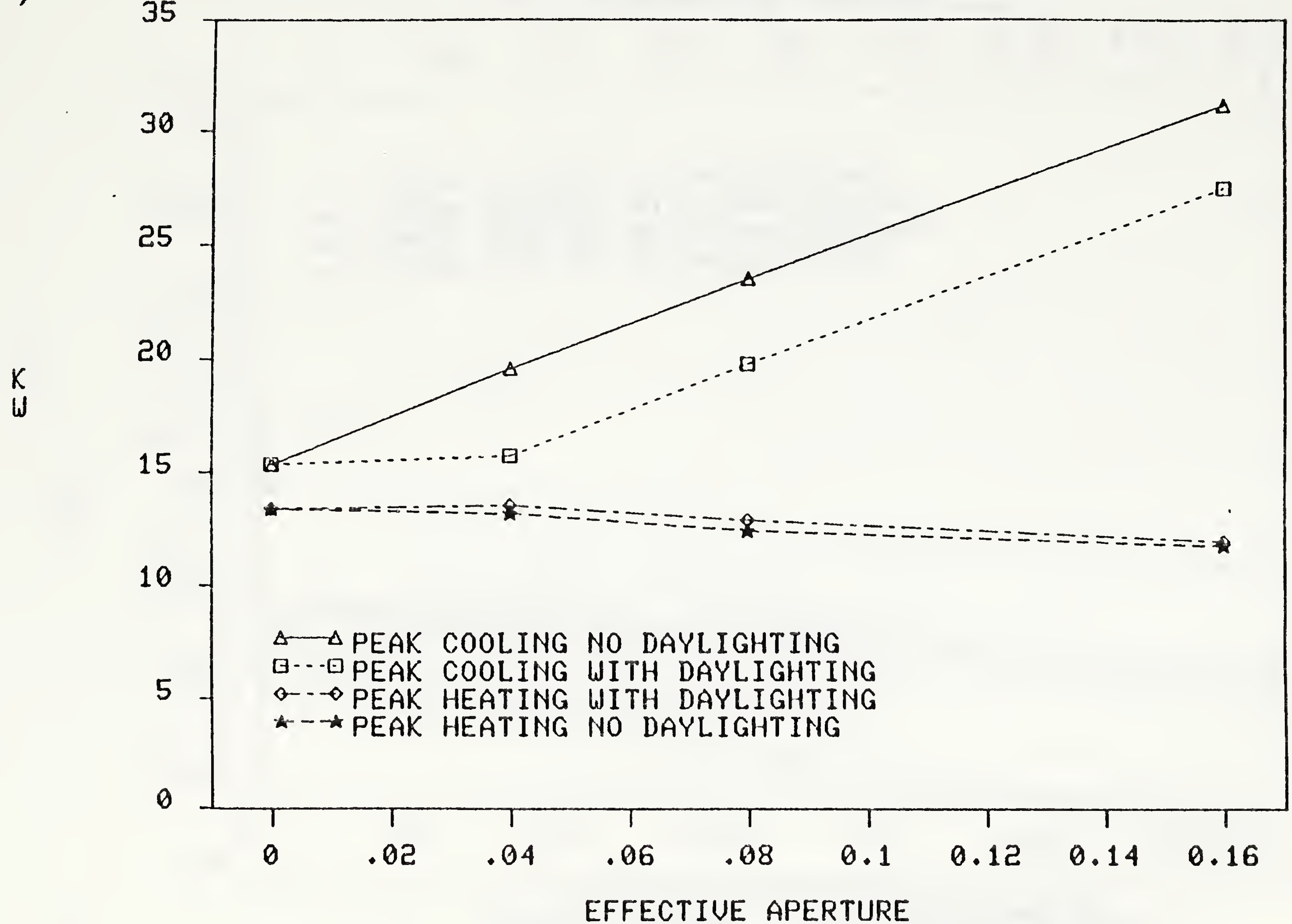


Figure 159. PEAK HEATING AND COOLING LOADS (San Diego)
NORTH SAWTOOTH, METAL FREESTANDING

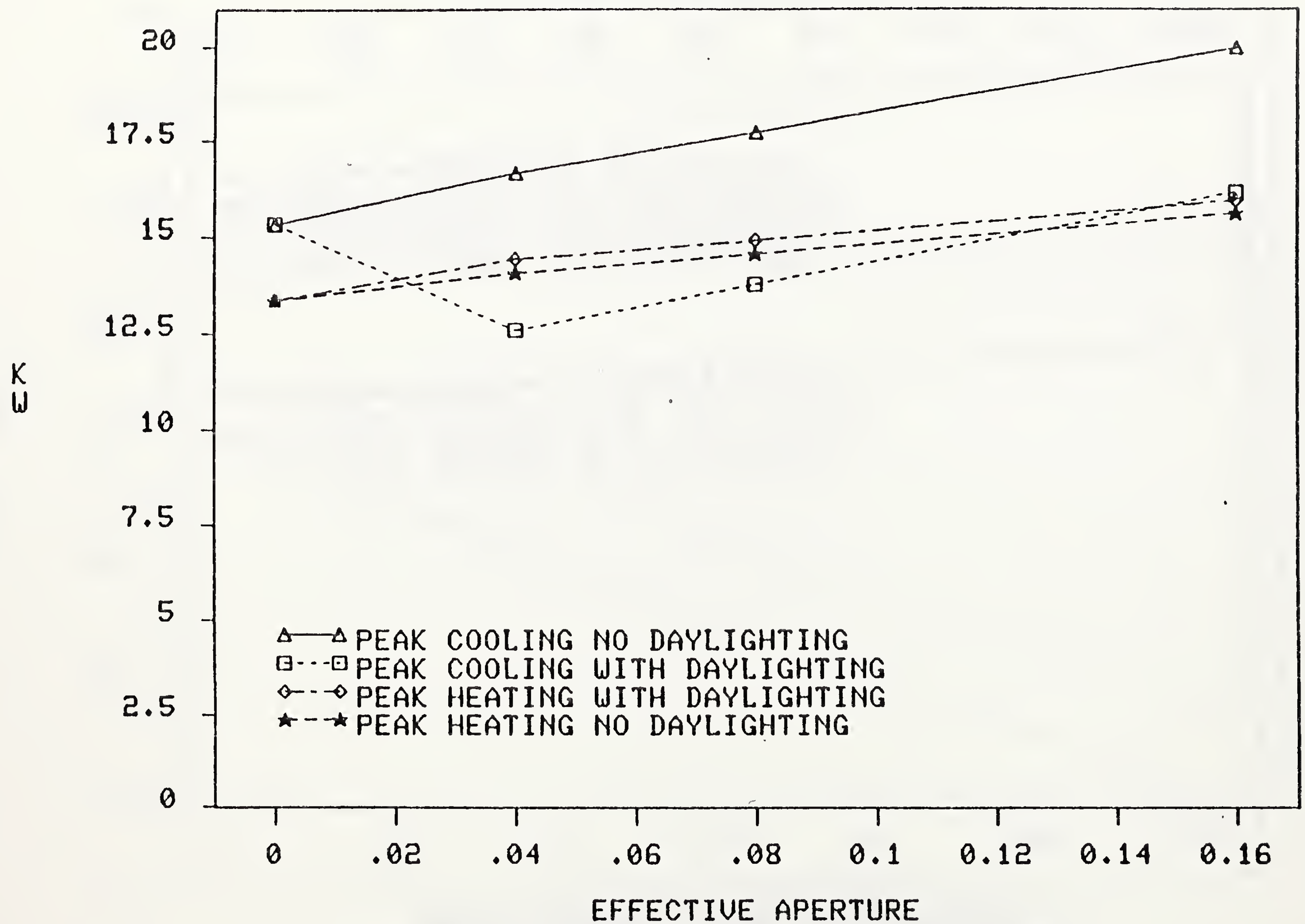


Figure 160. PEAK HEATING AND COOLING LOADS (San Diego) SOUTH WINDOW, METAL FREESTANDING

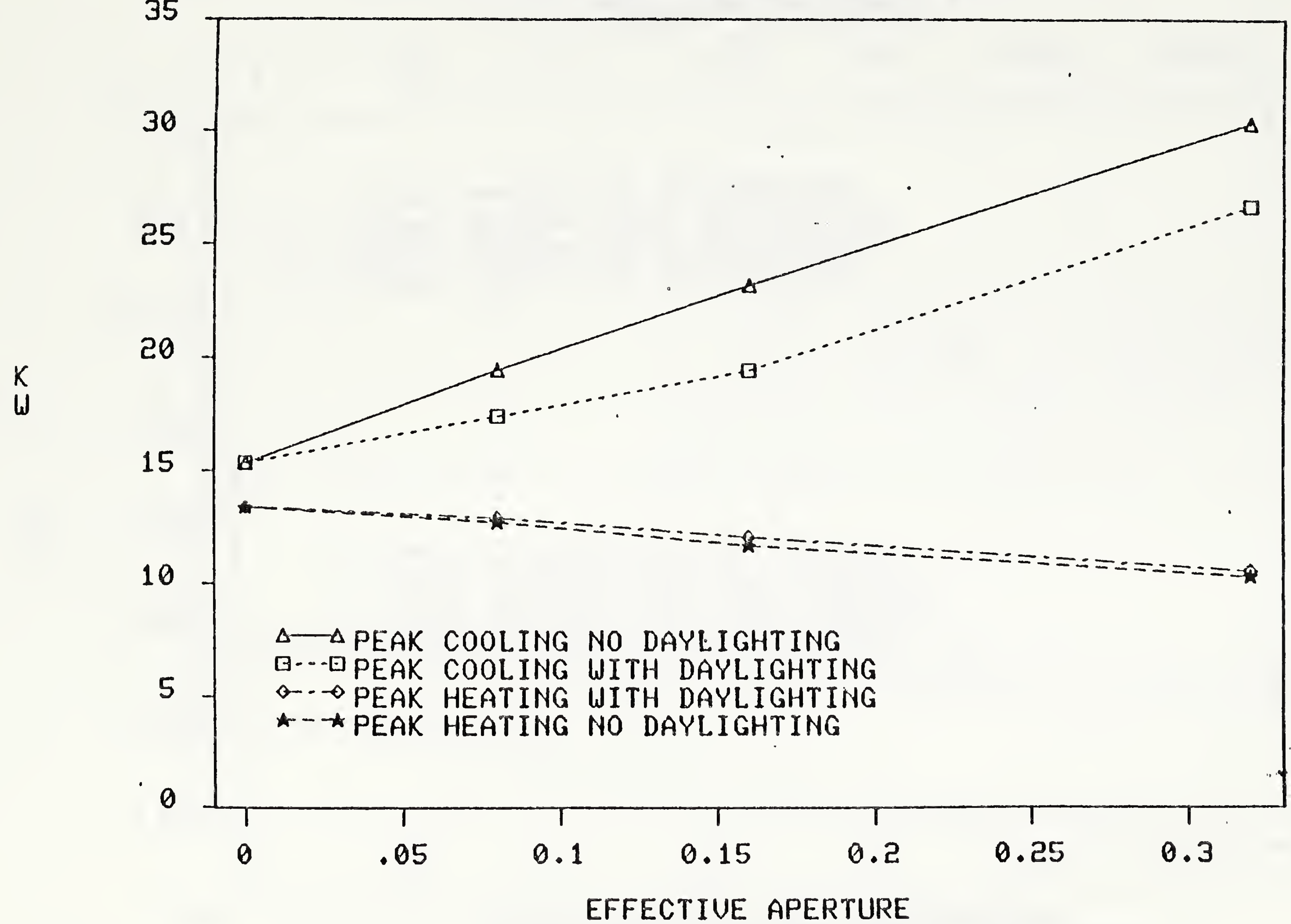


Figure 161. PEAK HEATING AND COOLING LOADS (San Diego)
NORTH WINDOW, METAL FREESTANDING

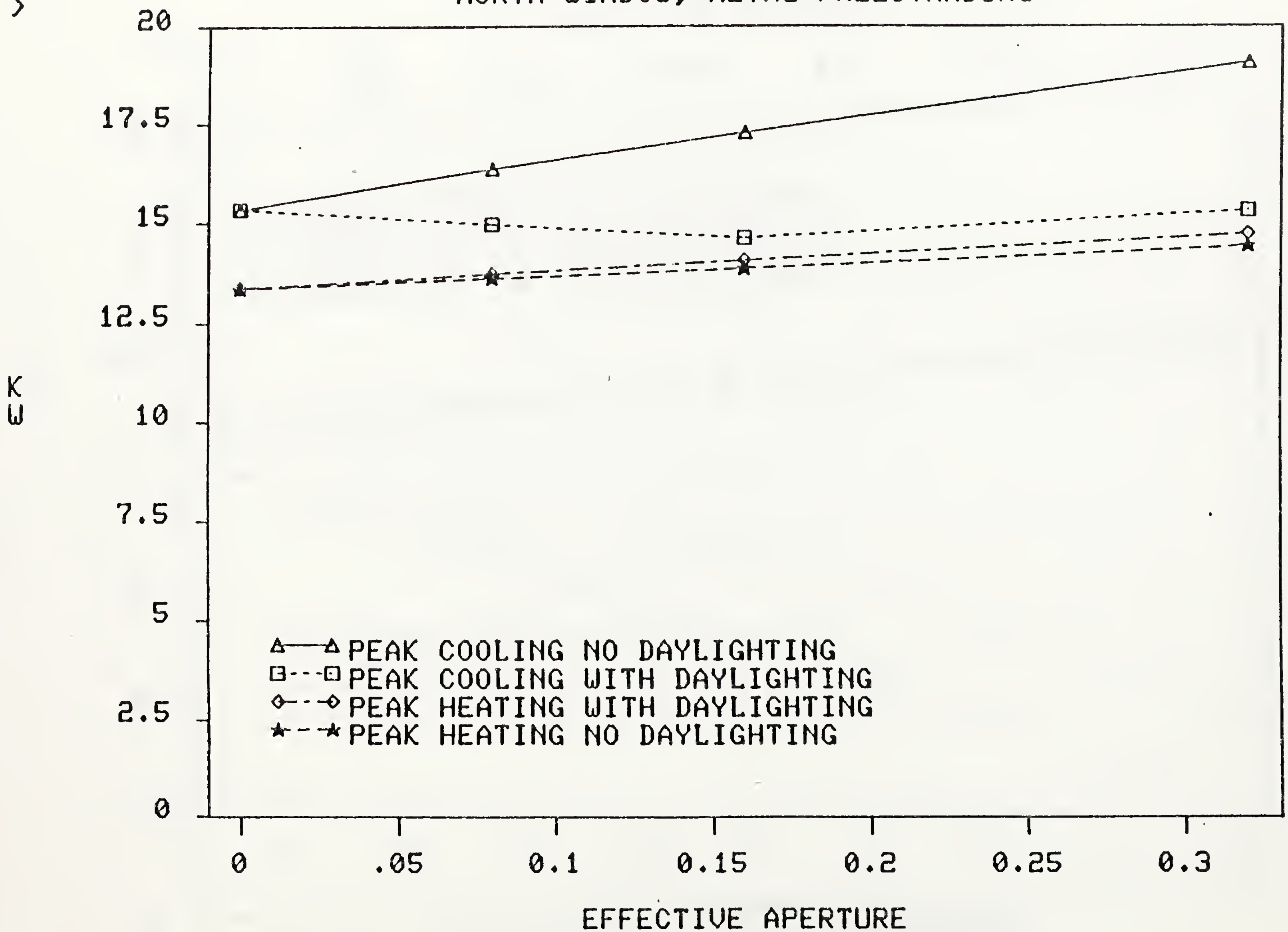


Figure 162. PEAK HEATING AND COOLING LOADS (San Diego)
SKYLIGHTS, METAL ATTACHED

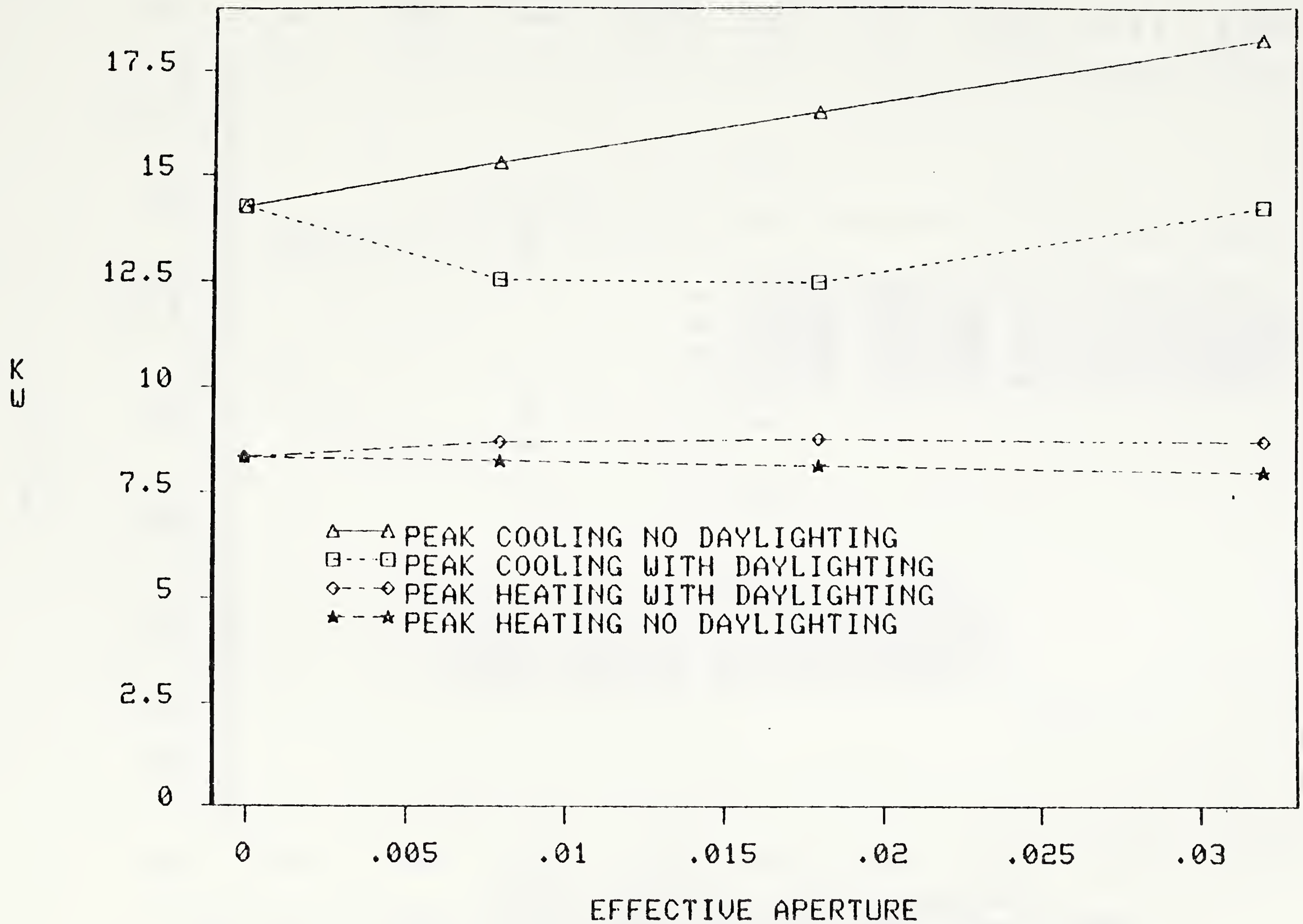


Figure 163. PEAK HEATING AND COOLING LOADS (San Diego)
SOUTH SAWTOOTH, METAL ATTACHED

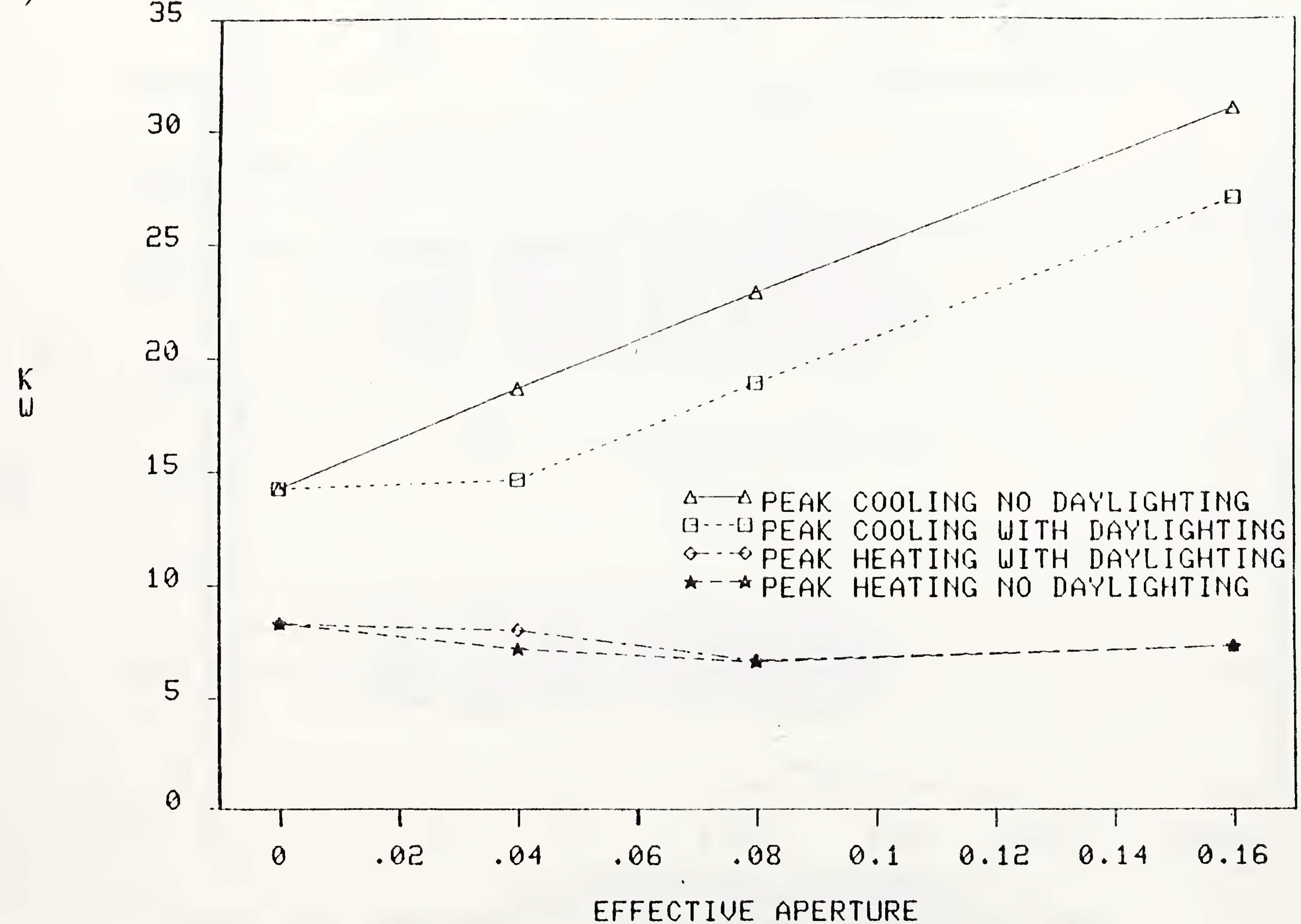


Figure 164. PEAK HEATING AND COOLING LOADS (San Diego)
NORTH SAWTOOTH, METAL ATTACHED

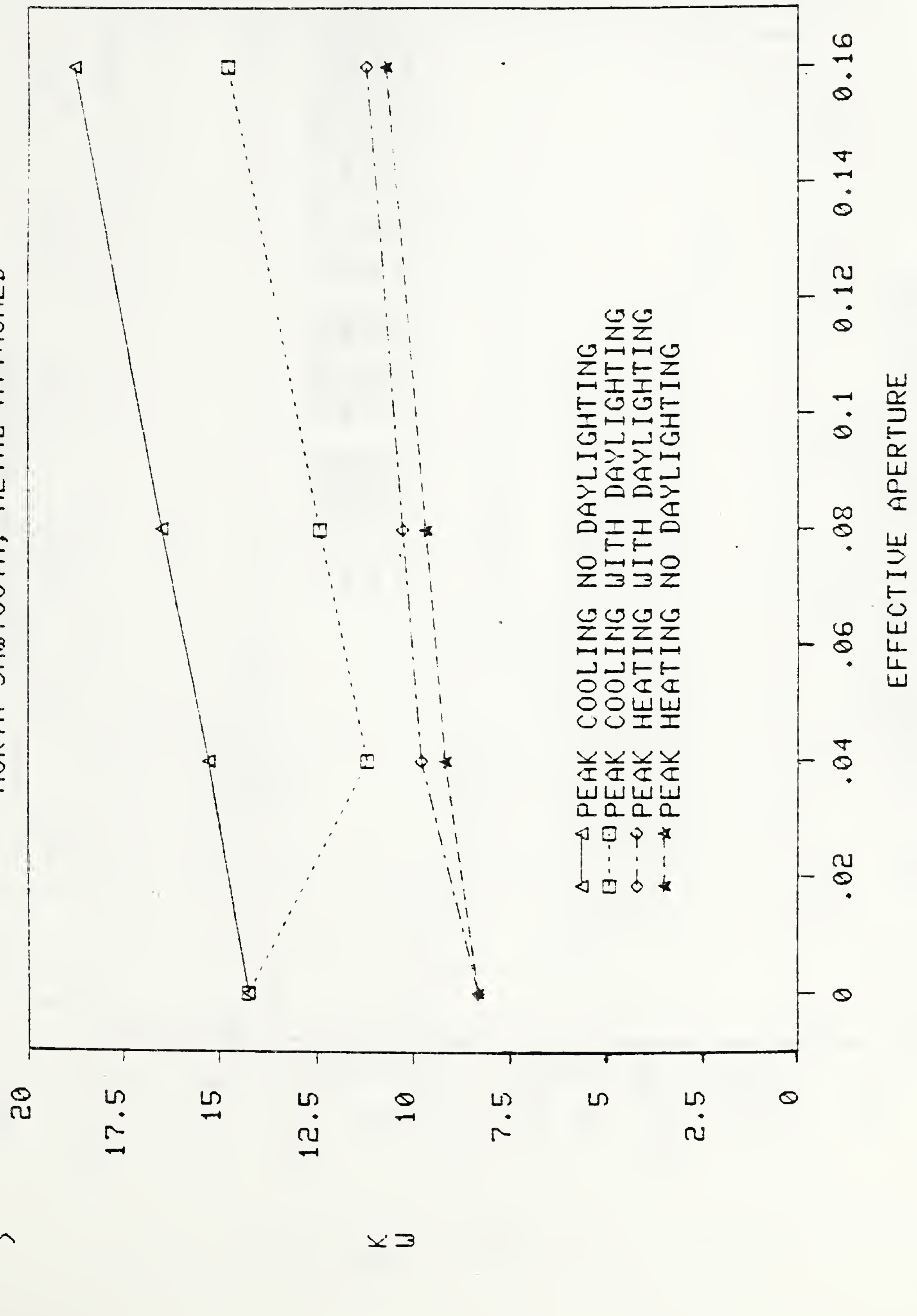


Figure 165. PEAK HEATING AND COOLING LOADS (San Diego)
SOUTH WINDOW, METAL ATTACHED

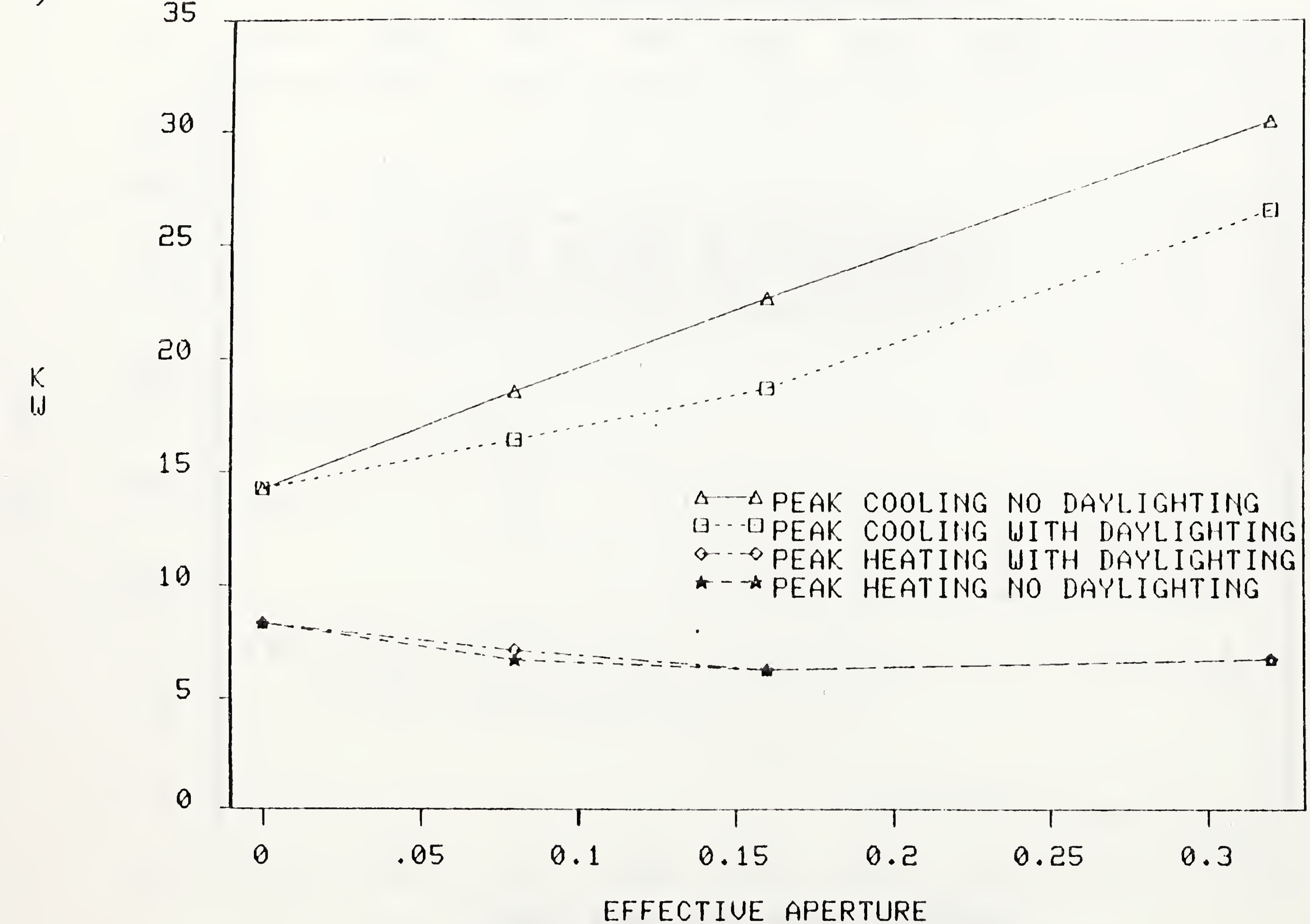


Figure 156. PEAK HEATING AND COOLING LOADS (San Diego)
NORTH WINDOW, METAL ATTACHED

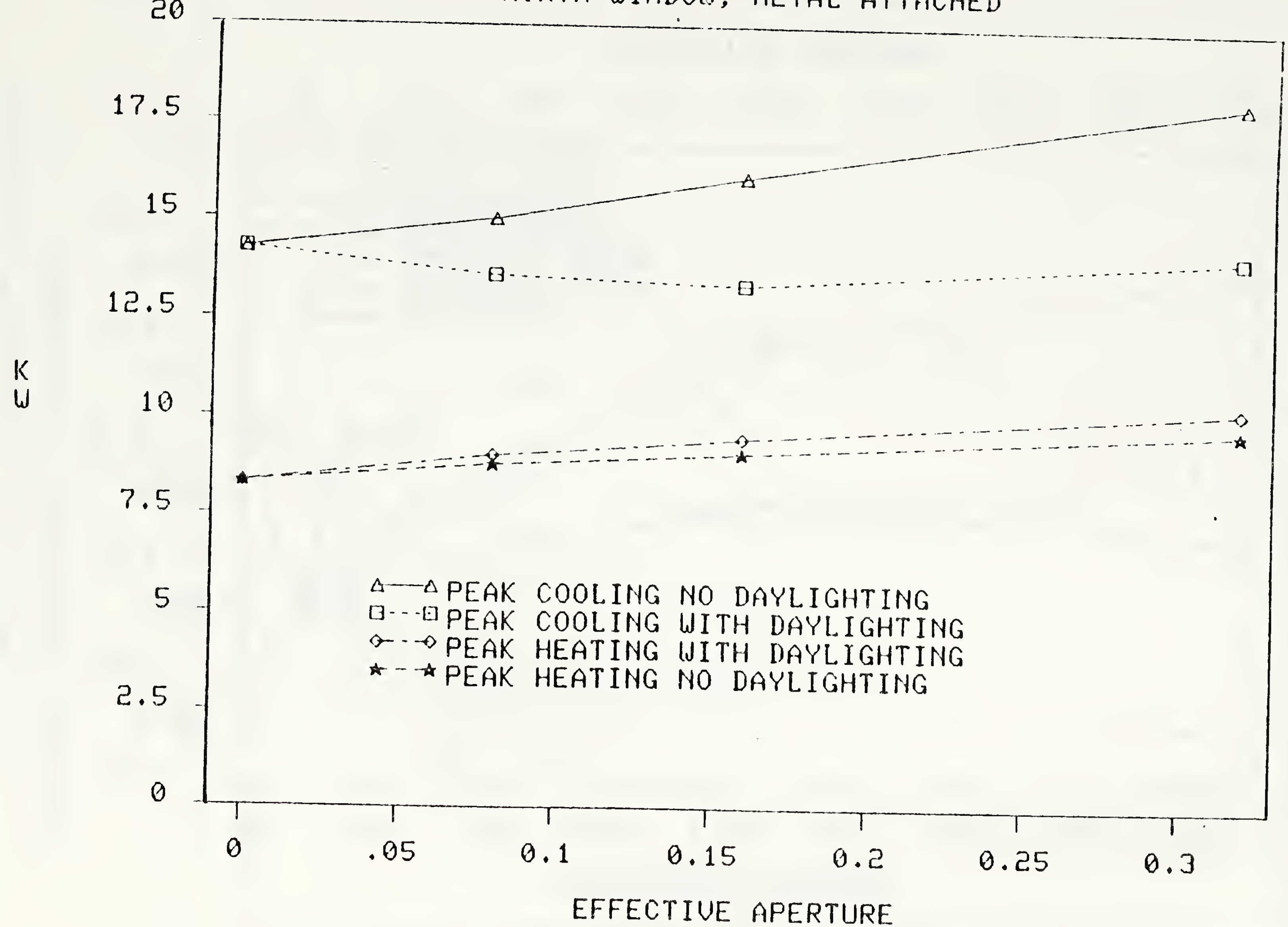


Figure 167. TOTAL ENERGY WITH DAYLIGHT (Norfolk)
BRICK FREESTANDING

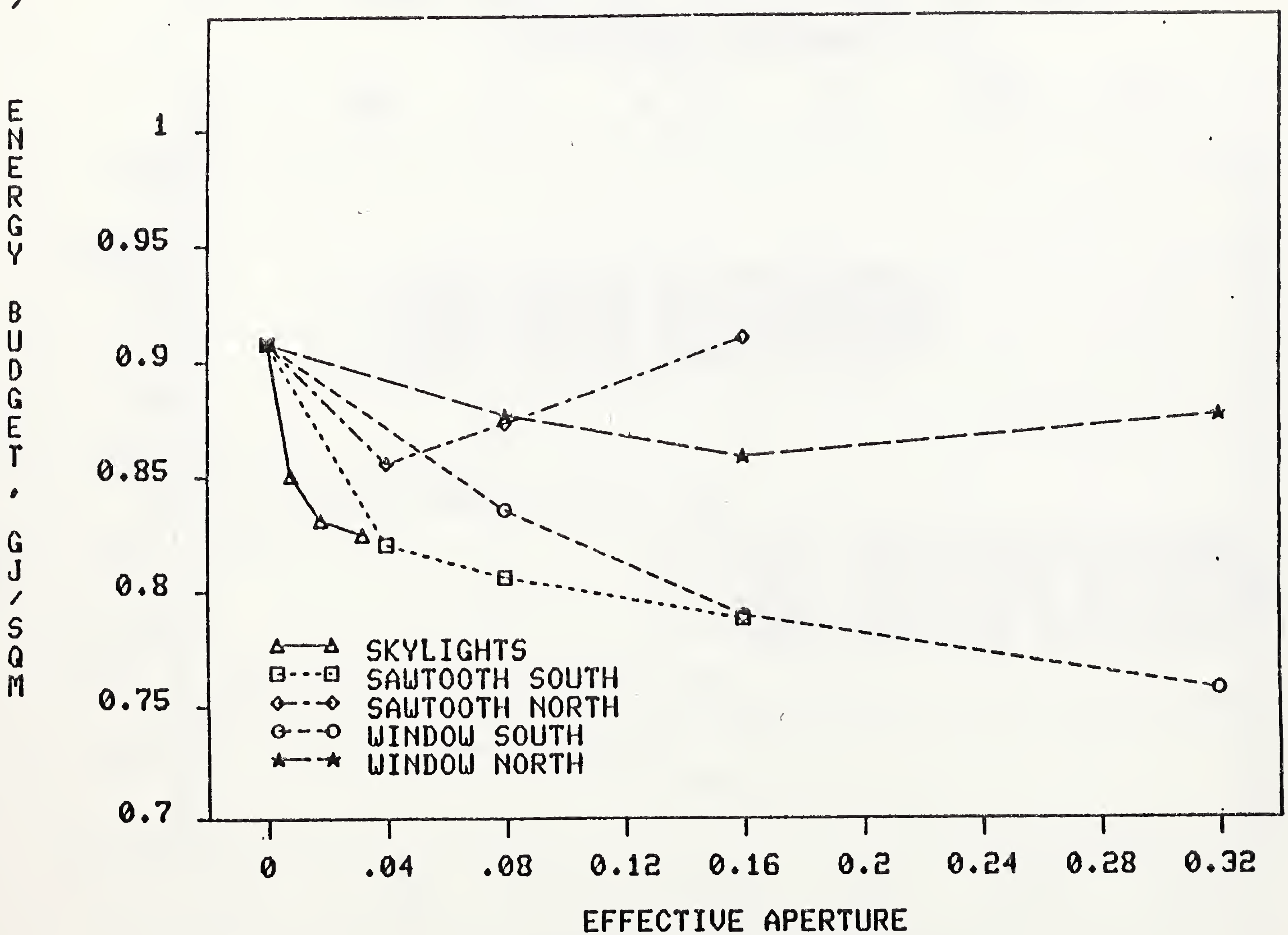


Figure 168. TOTAL ENERGY WITH DAYLIGHT (Norfolk)
BRICK ATTACHED

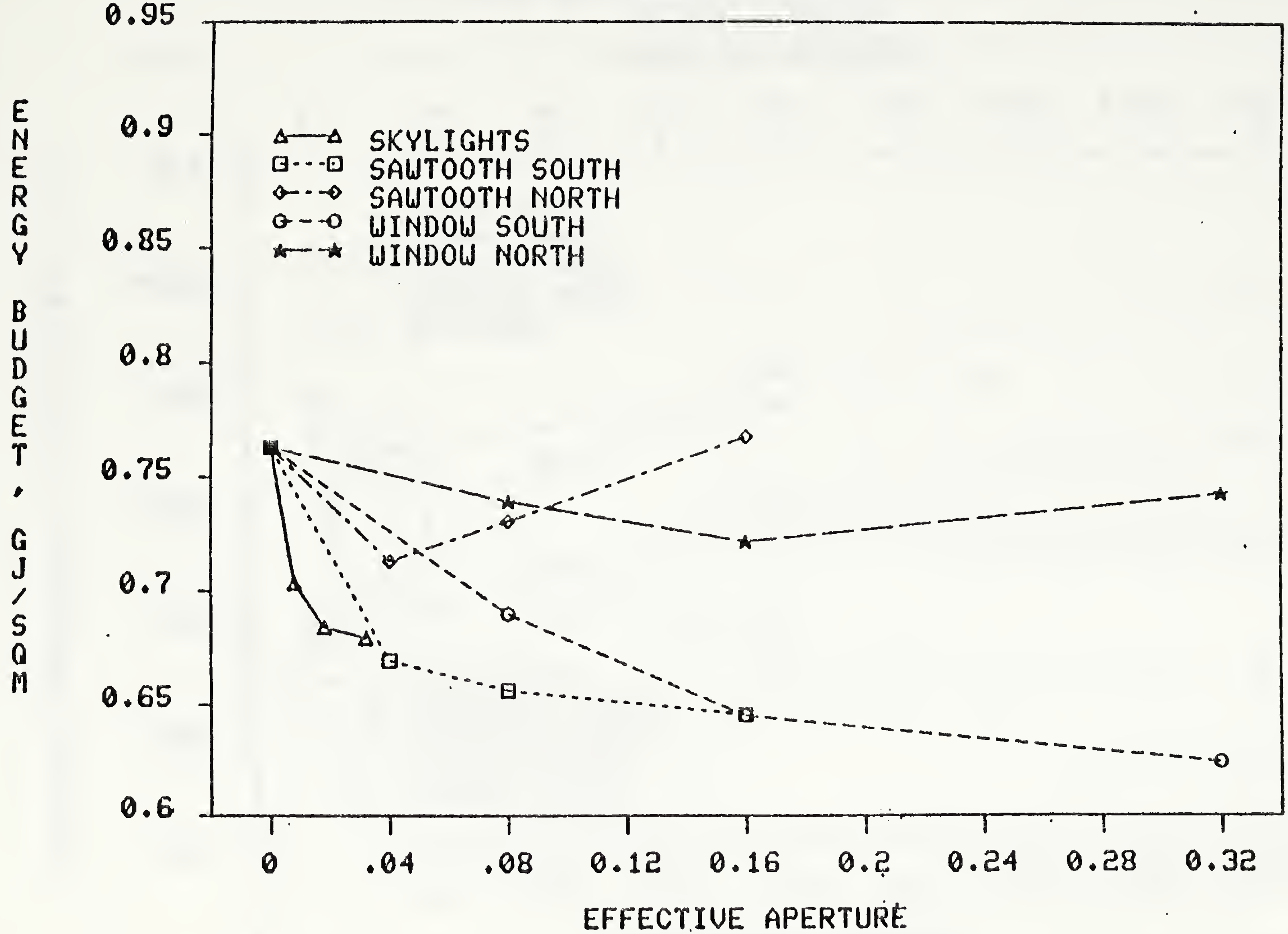


Figure 169. TOTAL ENERGY WITH DAYLIGHT (Norfolk)
METAL FREESTANDING

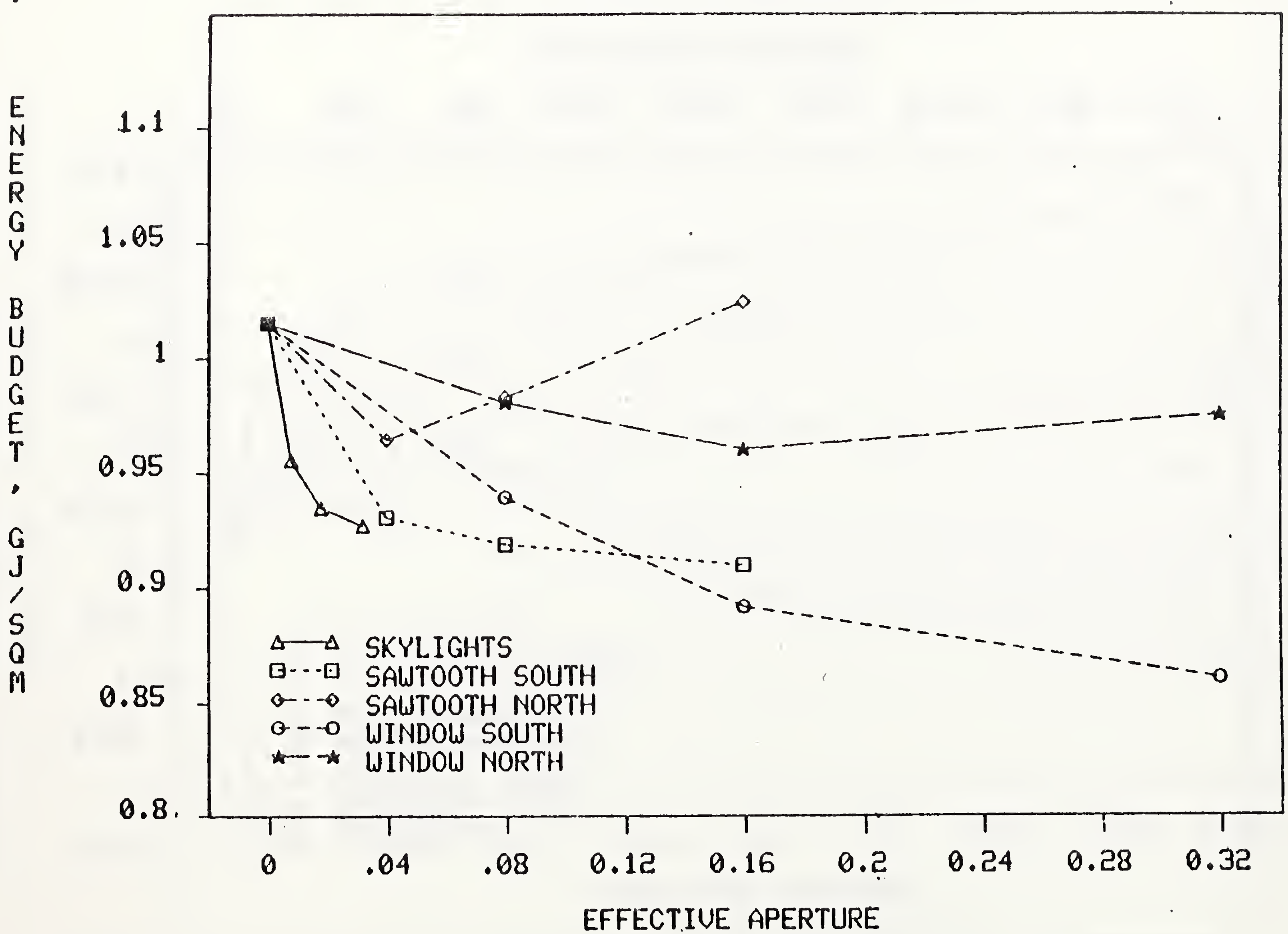


Figure 170. TOTAL ENERGY WITH DAYLIGHT (Norfolk)
METAL ATTACHED

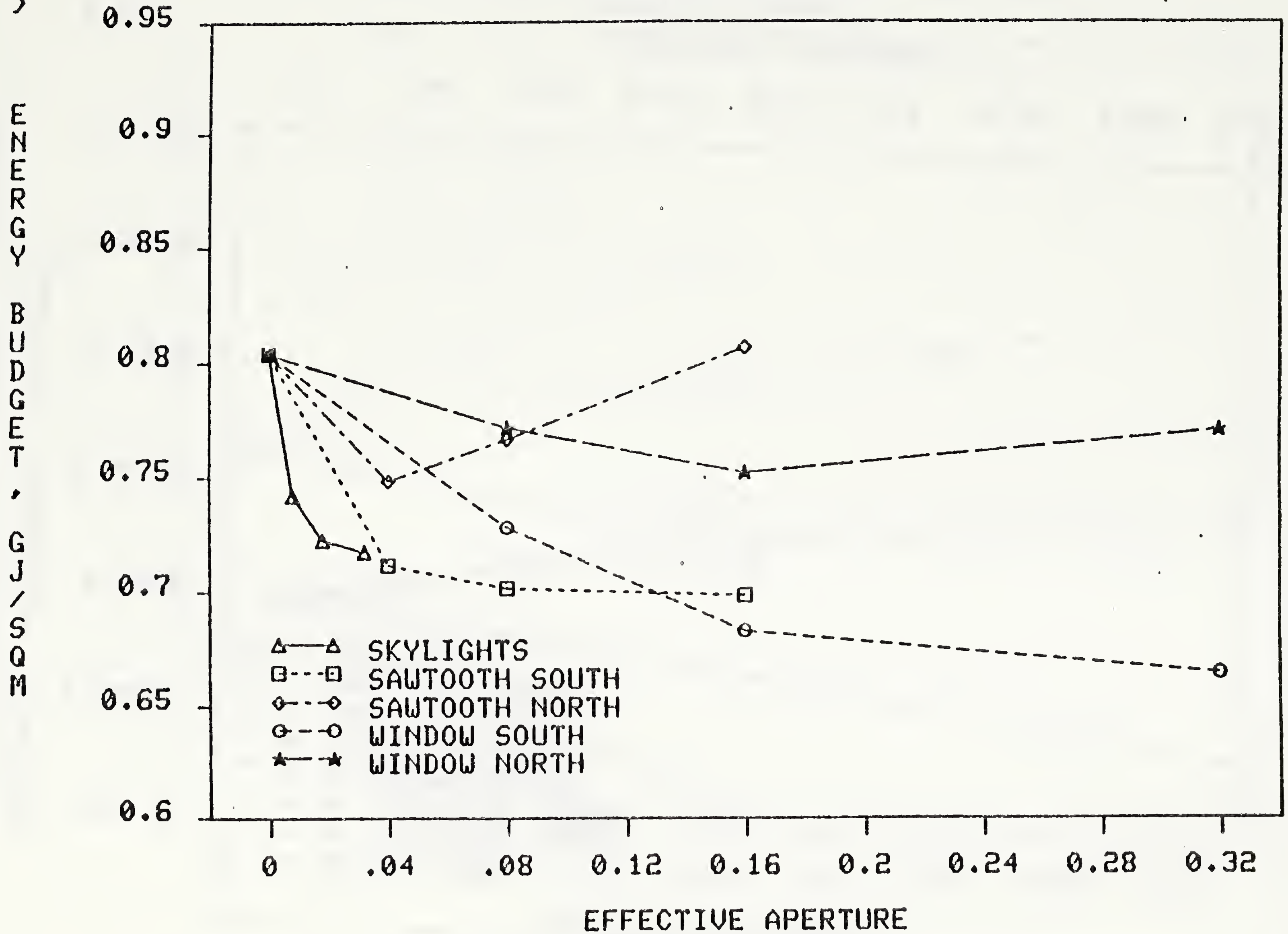


Figure 171. TOTAL ENERGY WITHOUT DAYLIGHT (Norfolk)
BRICK FREESTANDING

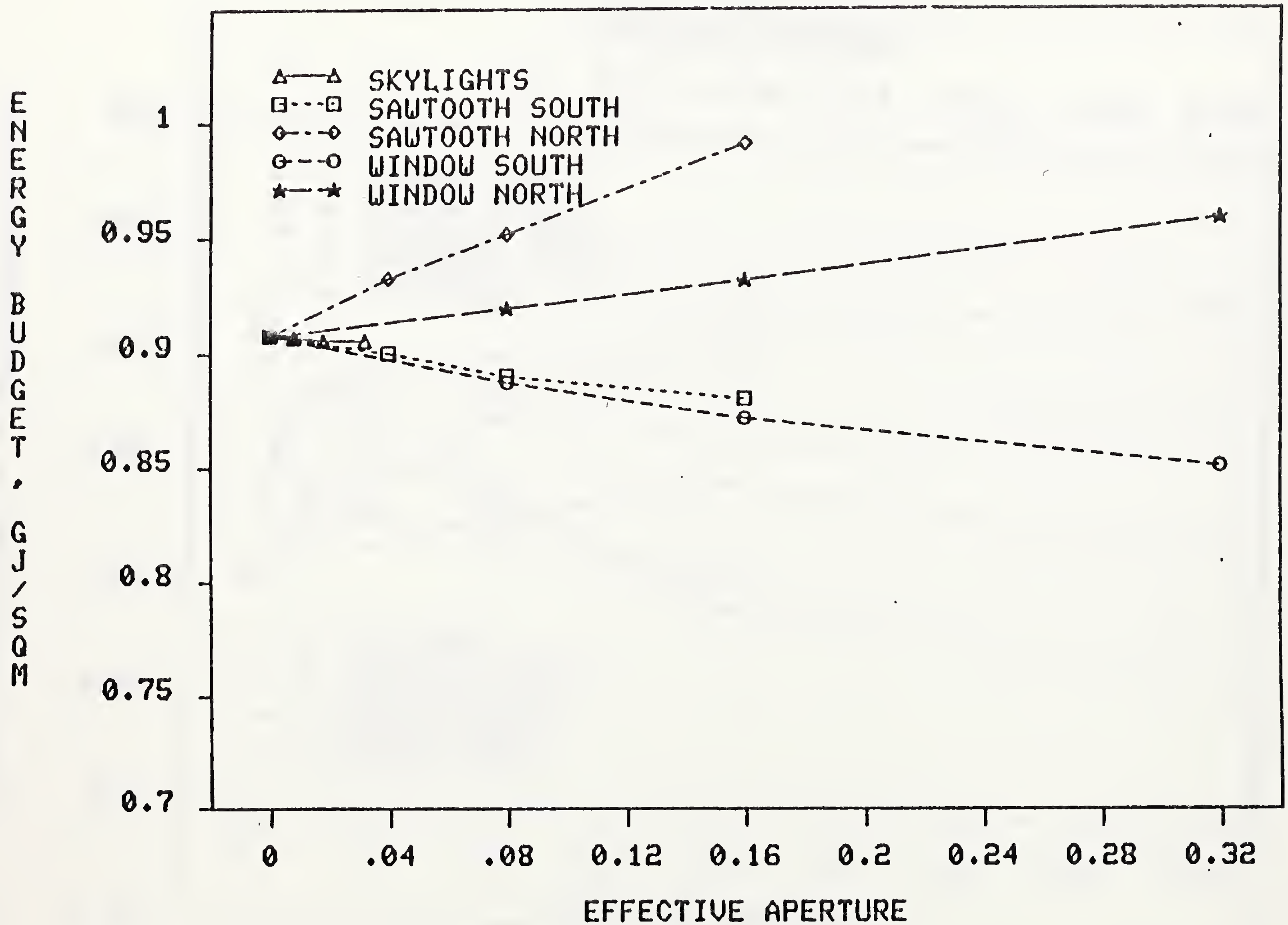


Figure 172. TOTAL ENERGY WITHOUT DAYLIGHT (Norfolk) BRICK ATTACHED

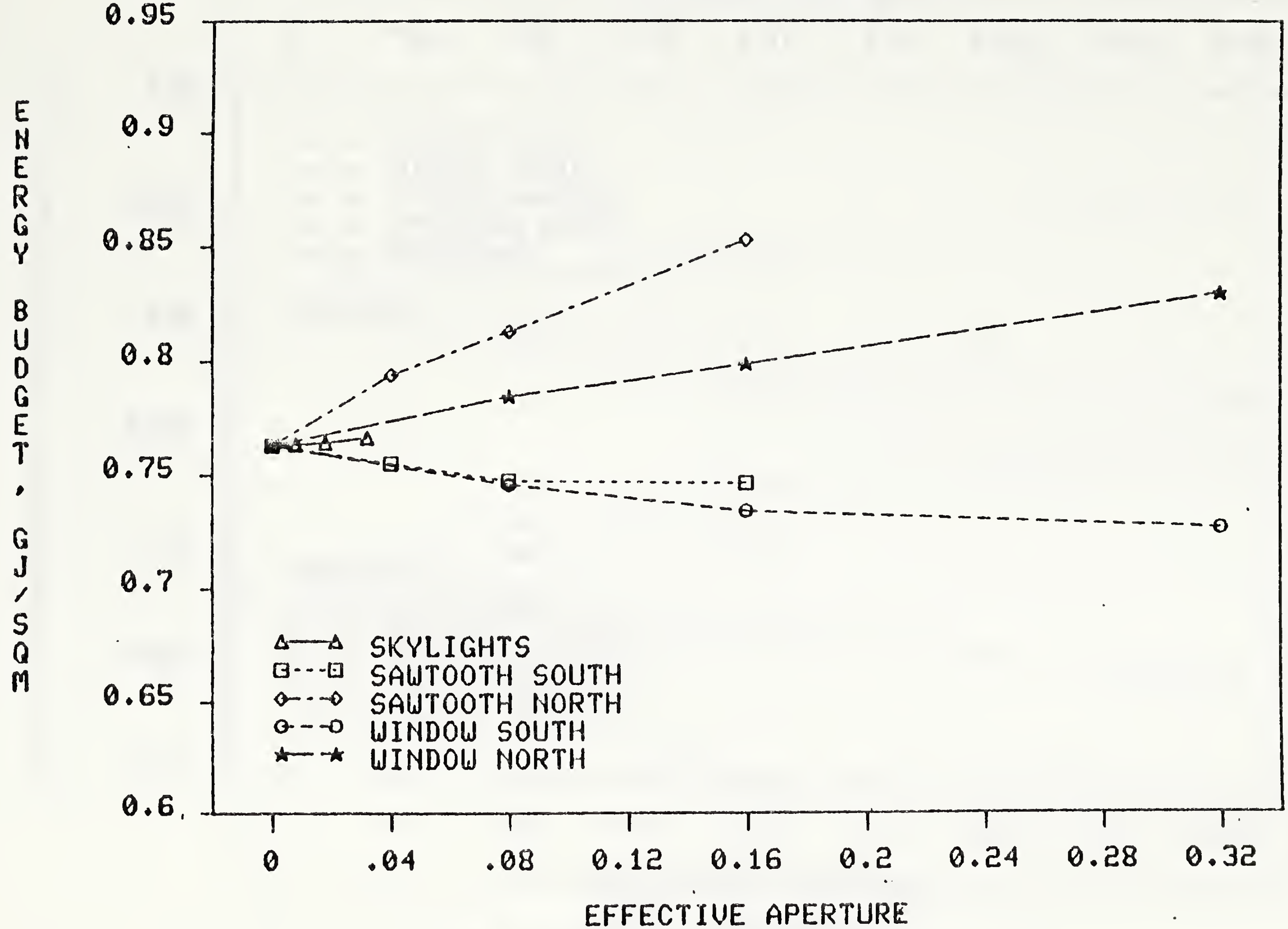


Figure 173. TOTAL ENERGY WITHOUT DAYLIGHT (Norfolk)
METAL FREESTANDING

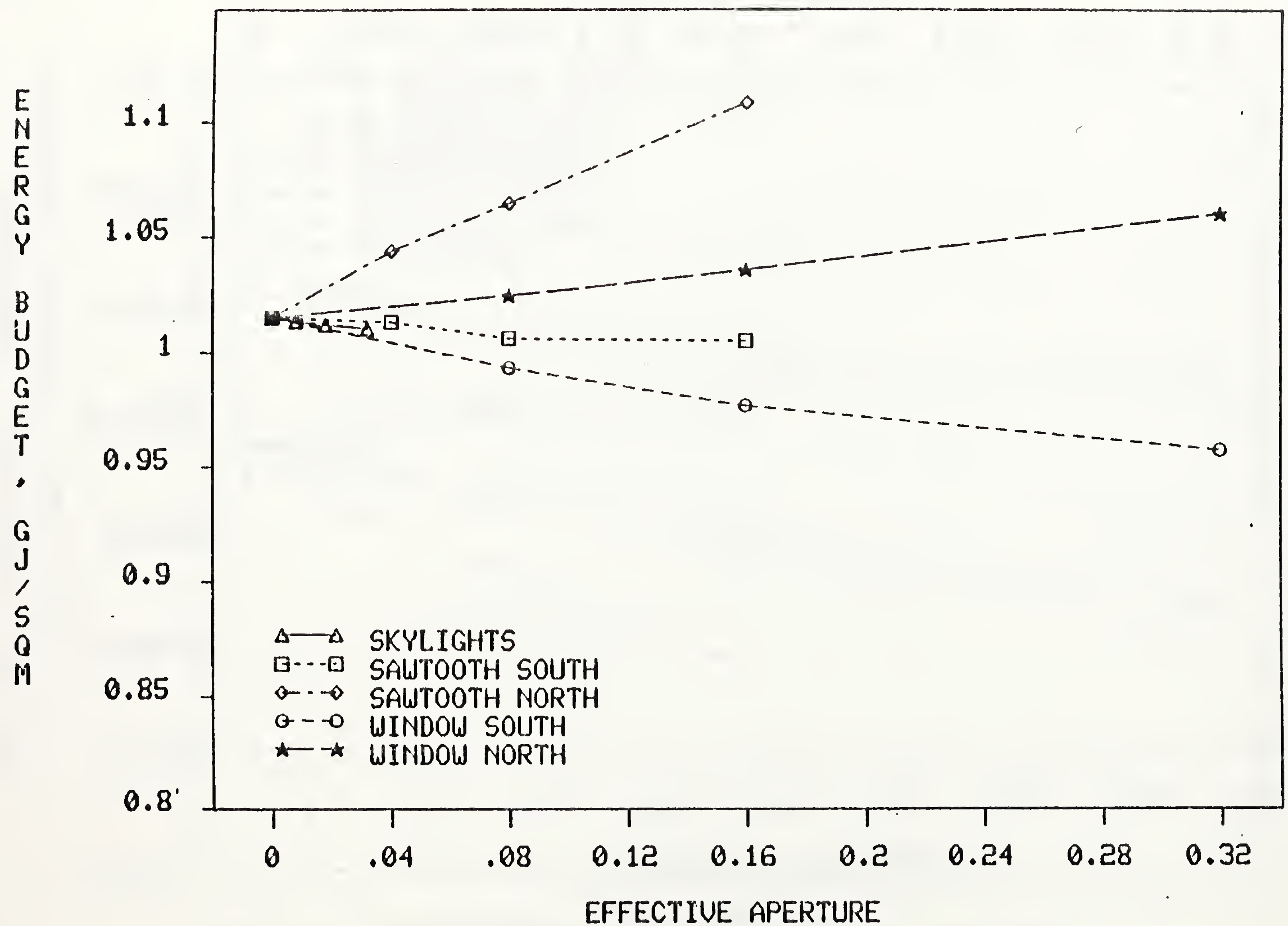


Figure 174. TOTAL ENERGY WITHOUT DAYLIGHT (Norfolk)
METAL ATTACHED

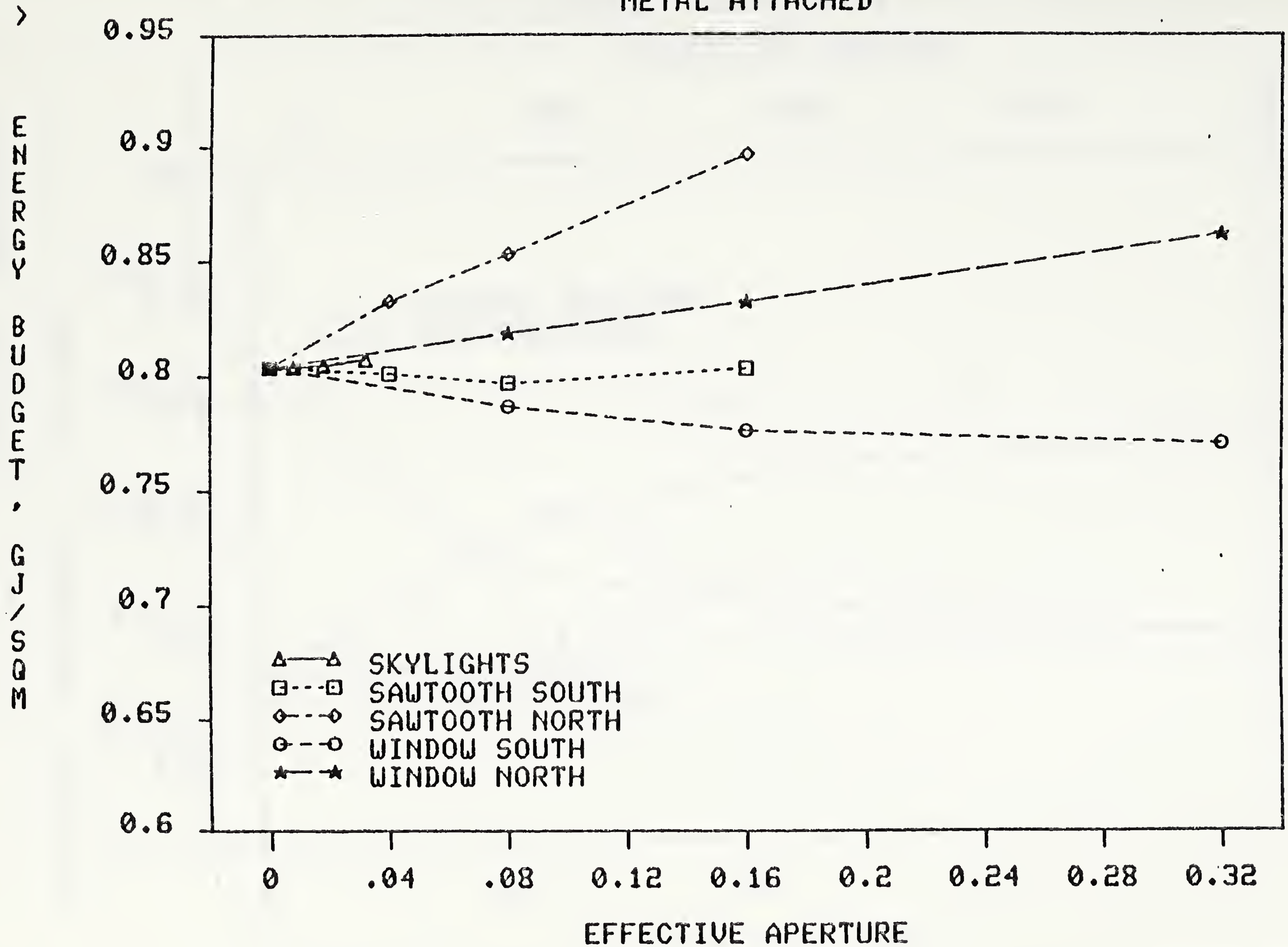


Figure 175. TOTAL ENERGY - SKYLIGHTS (Norfolk)
BRICK FREESTANDING

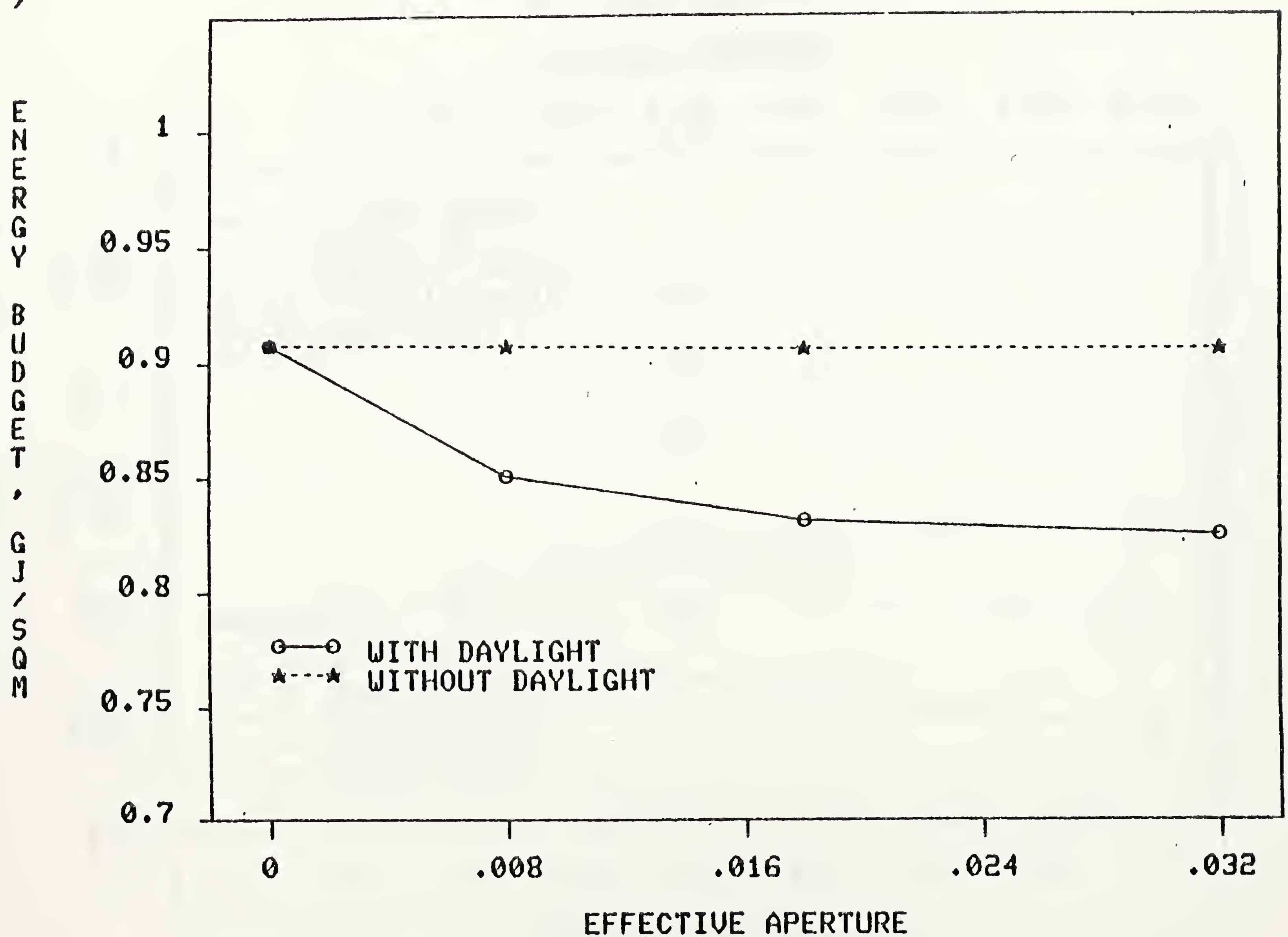


Figure :76. TOTAL ENERGY - SOUTH SAWTOOTH (Norfolk)
BRICK FREESTANDING

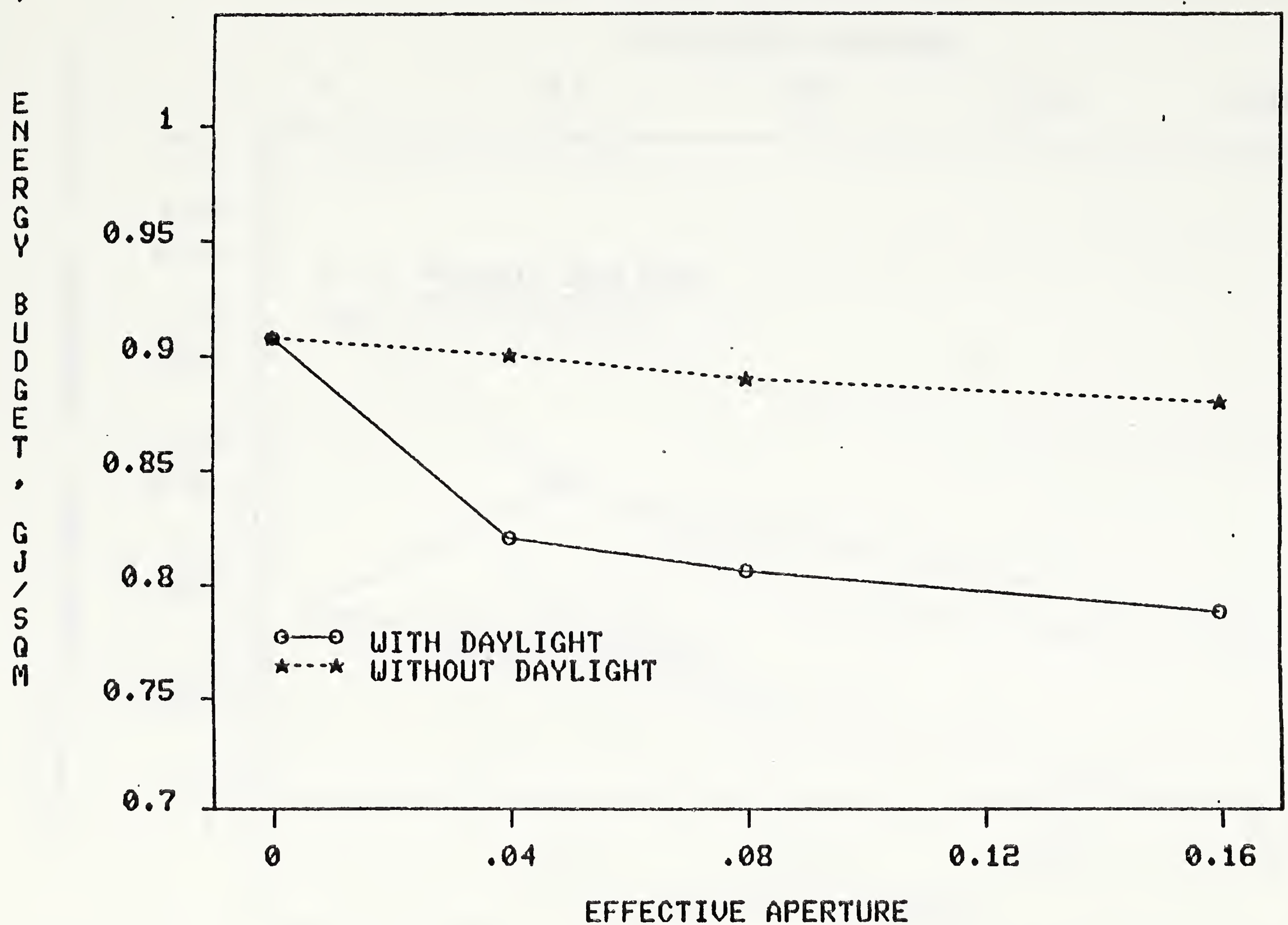


Figure 177. TOTAL ENERGY - NORTH SAWTOOTH (Norfolk)
BRICK FREESTANDING

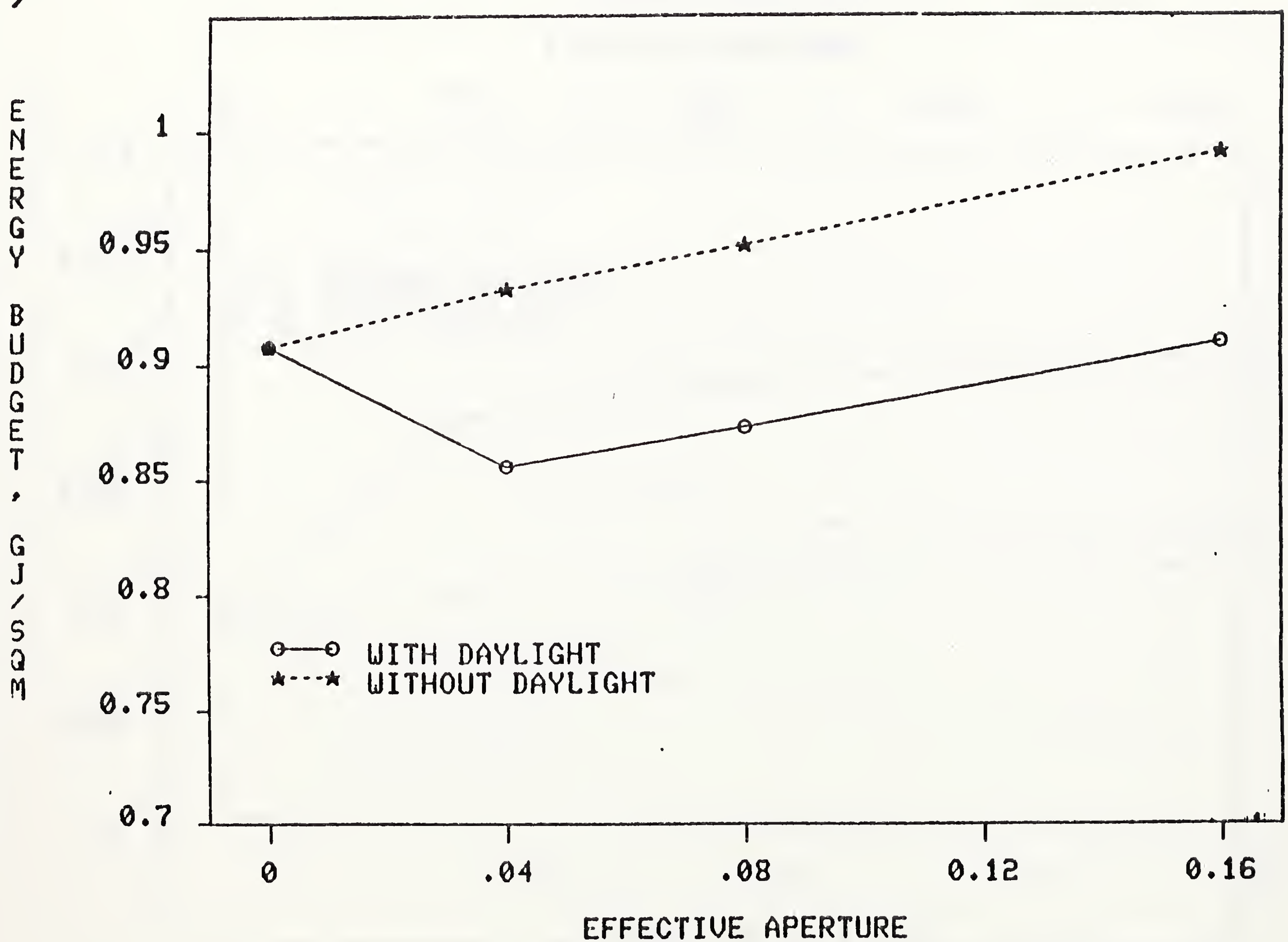


Figure 178. TOTAL ENERGY - SOUTH WINIOW (Norfolk)
BRICK FREESTANDING

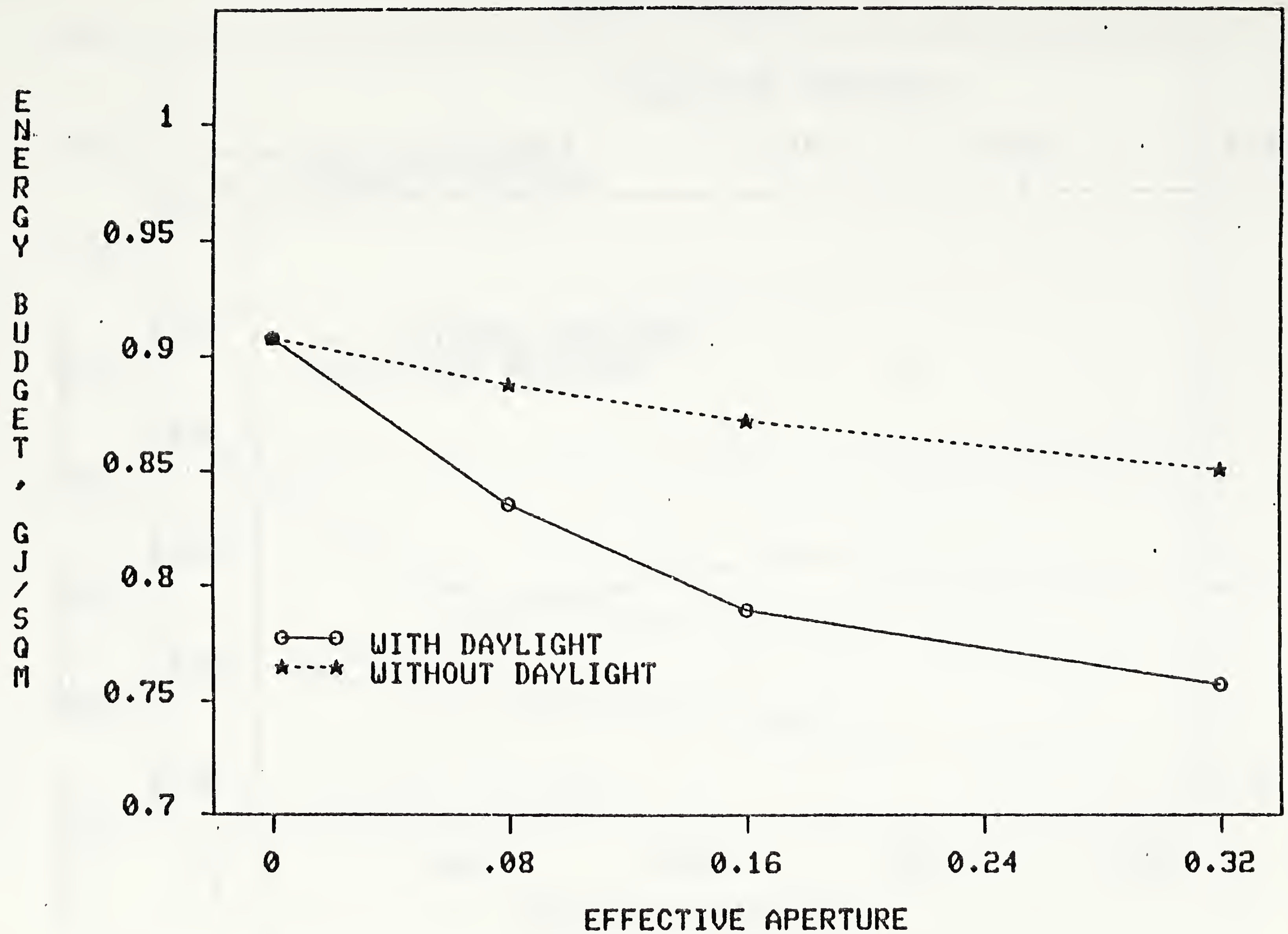


Figure 177. TOTAL ENERGY - NORTH WINDOW (Norfolk)
BRICK FREESTANDING

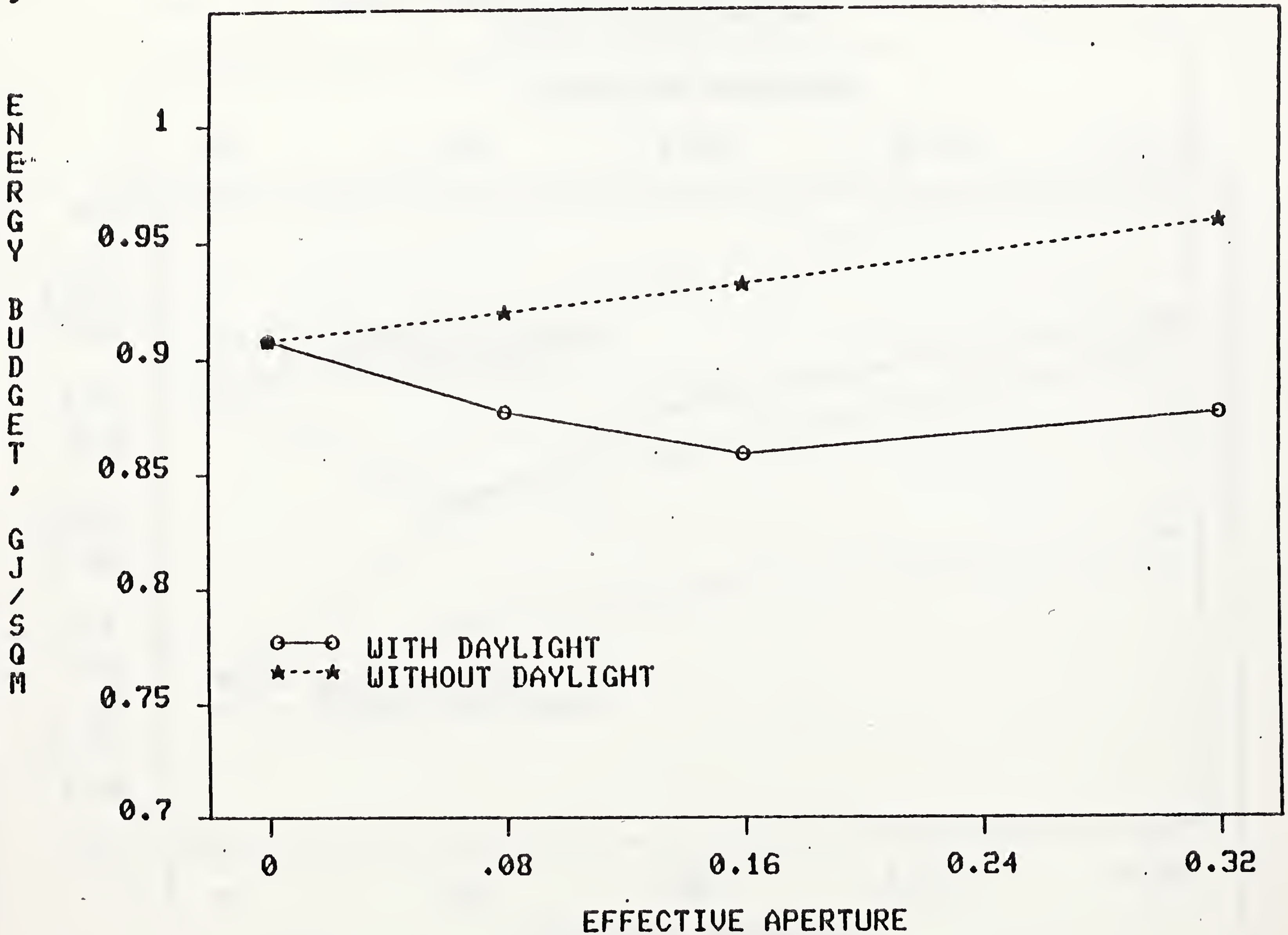


Figure 180. TOTAL ENERGY - SKYLIGHTS (Norfolk)
BRICK ATTACHED

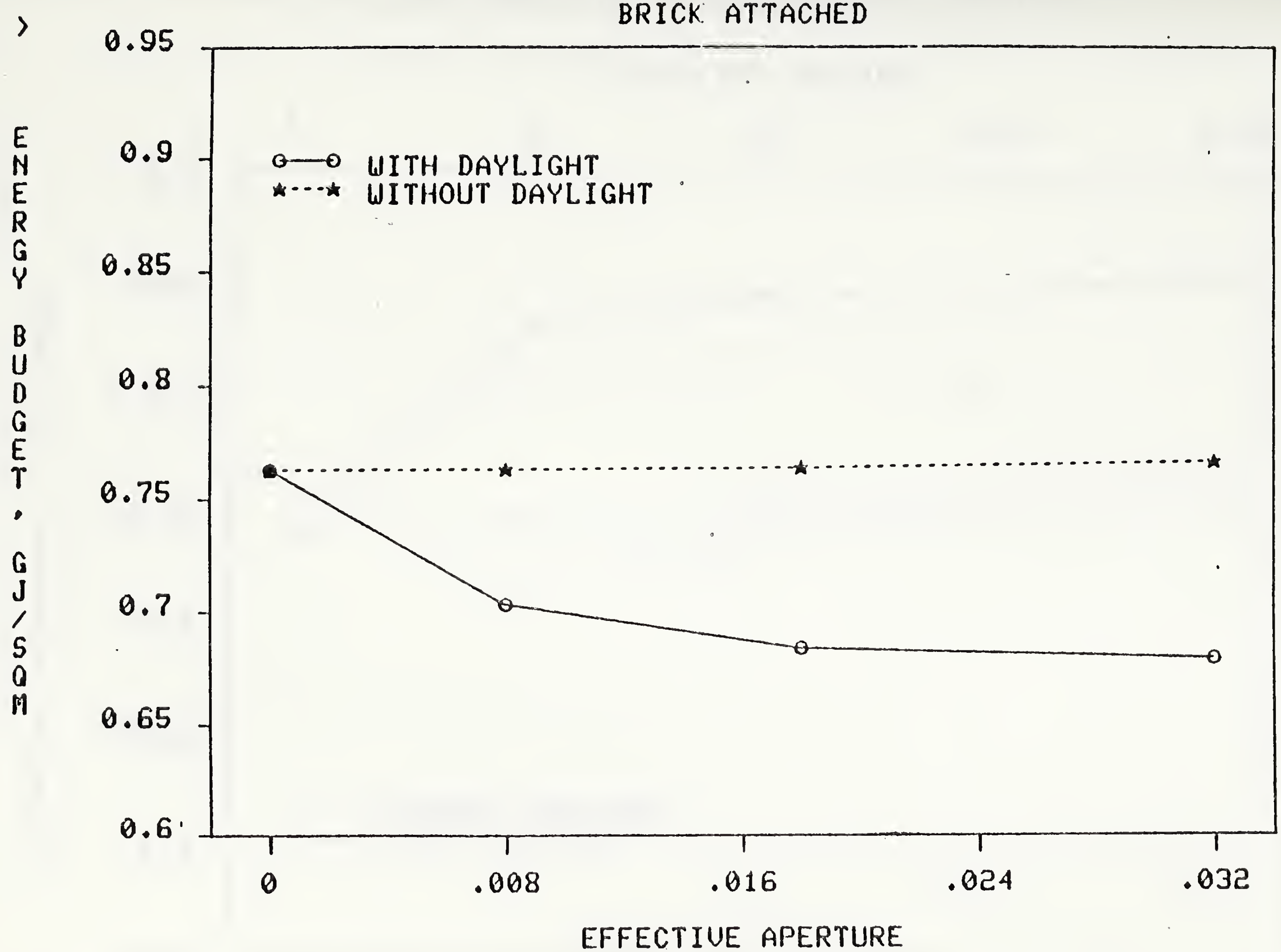


Figure 181. TOTAL ENERGY - SOUTH SAWTOOTH (Norfolk)
BRICK ATTACHED

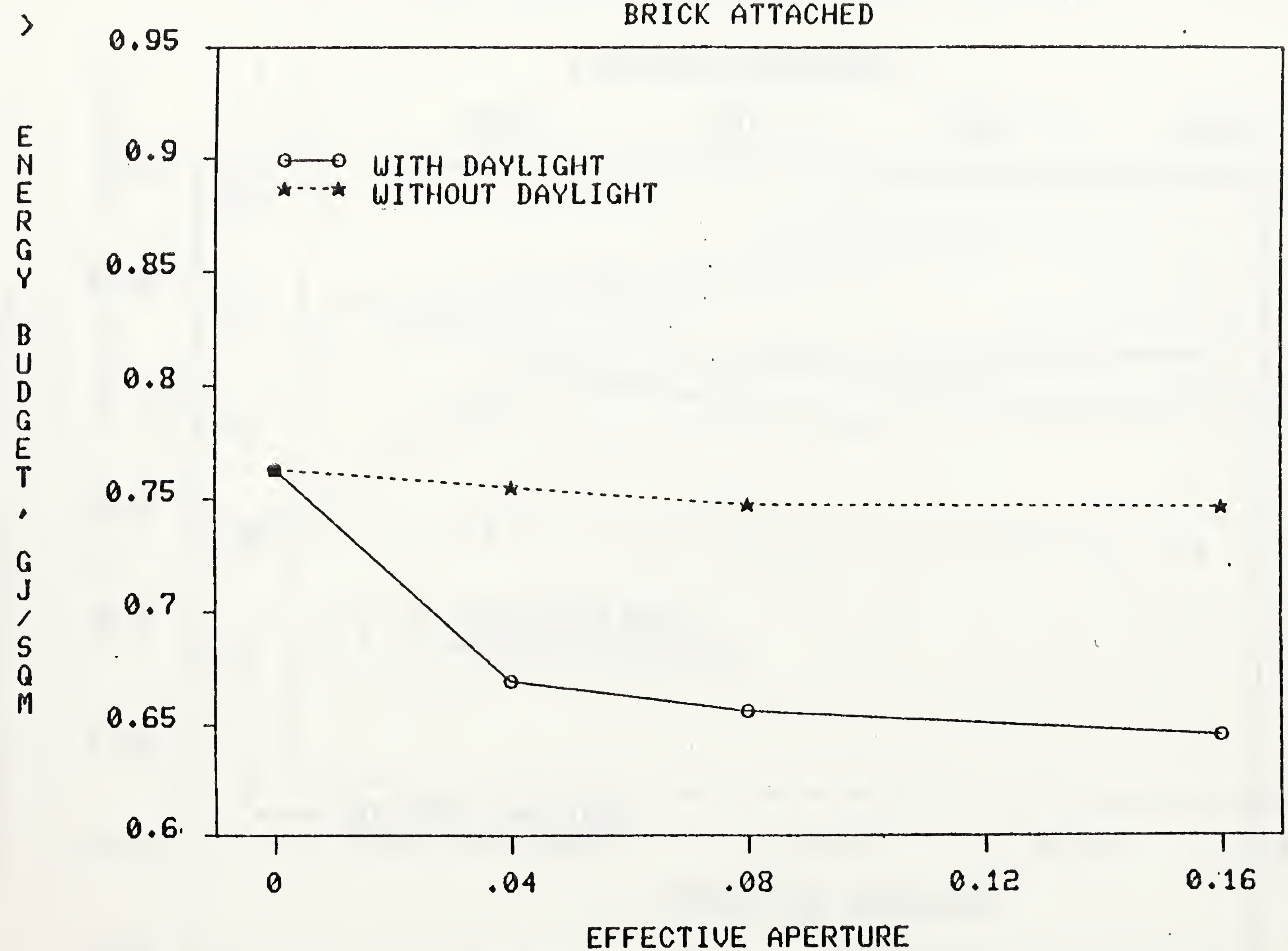


Figure 182. TOTAL ENERGY - NORTH SAWTOOTH (Norfolk)
BRICK ATTACHED

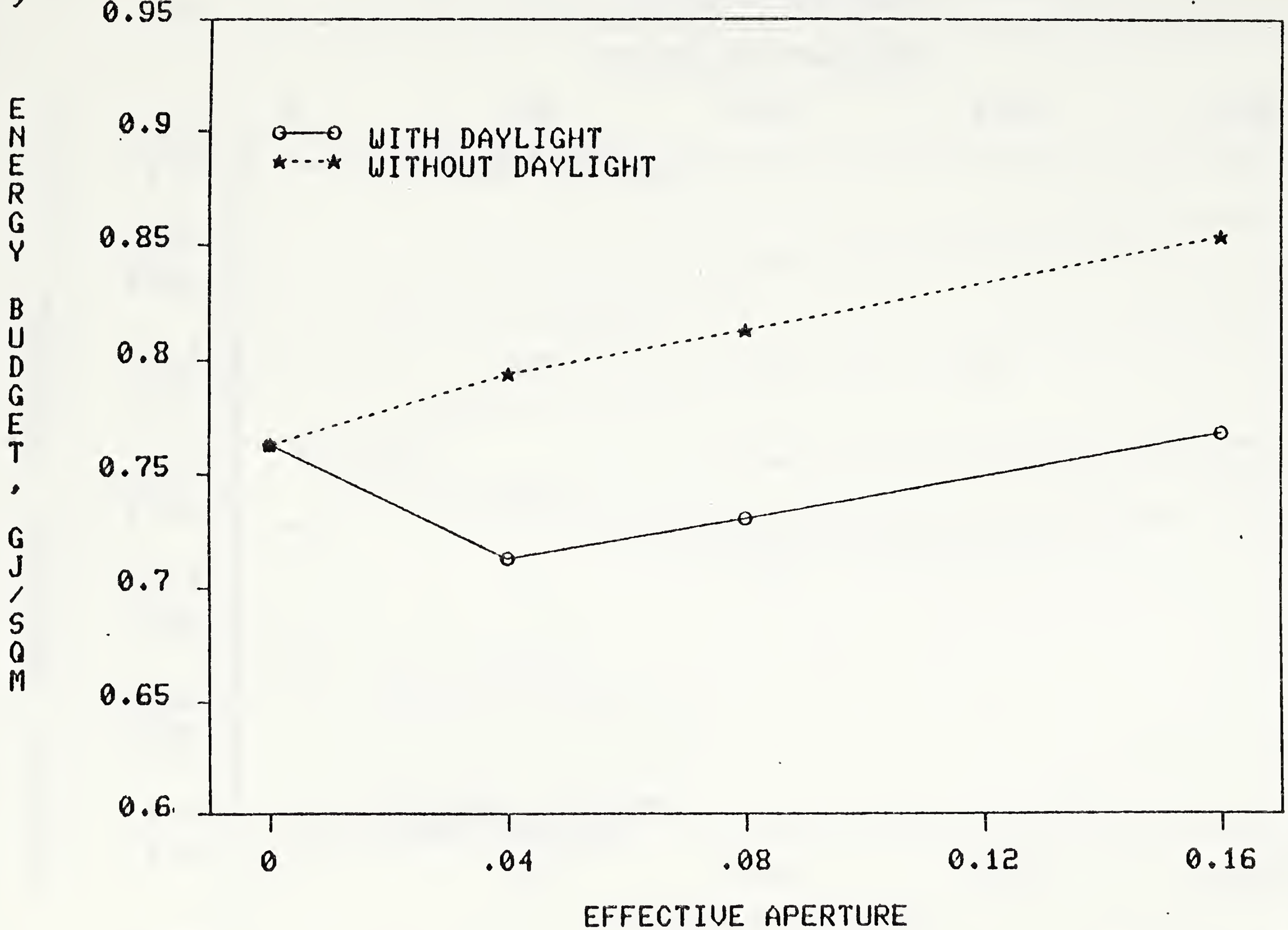


Figure 183. TOTAL ENERGY - SOUTH WINDOW (Norfolk)
BRICK ATTACHED

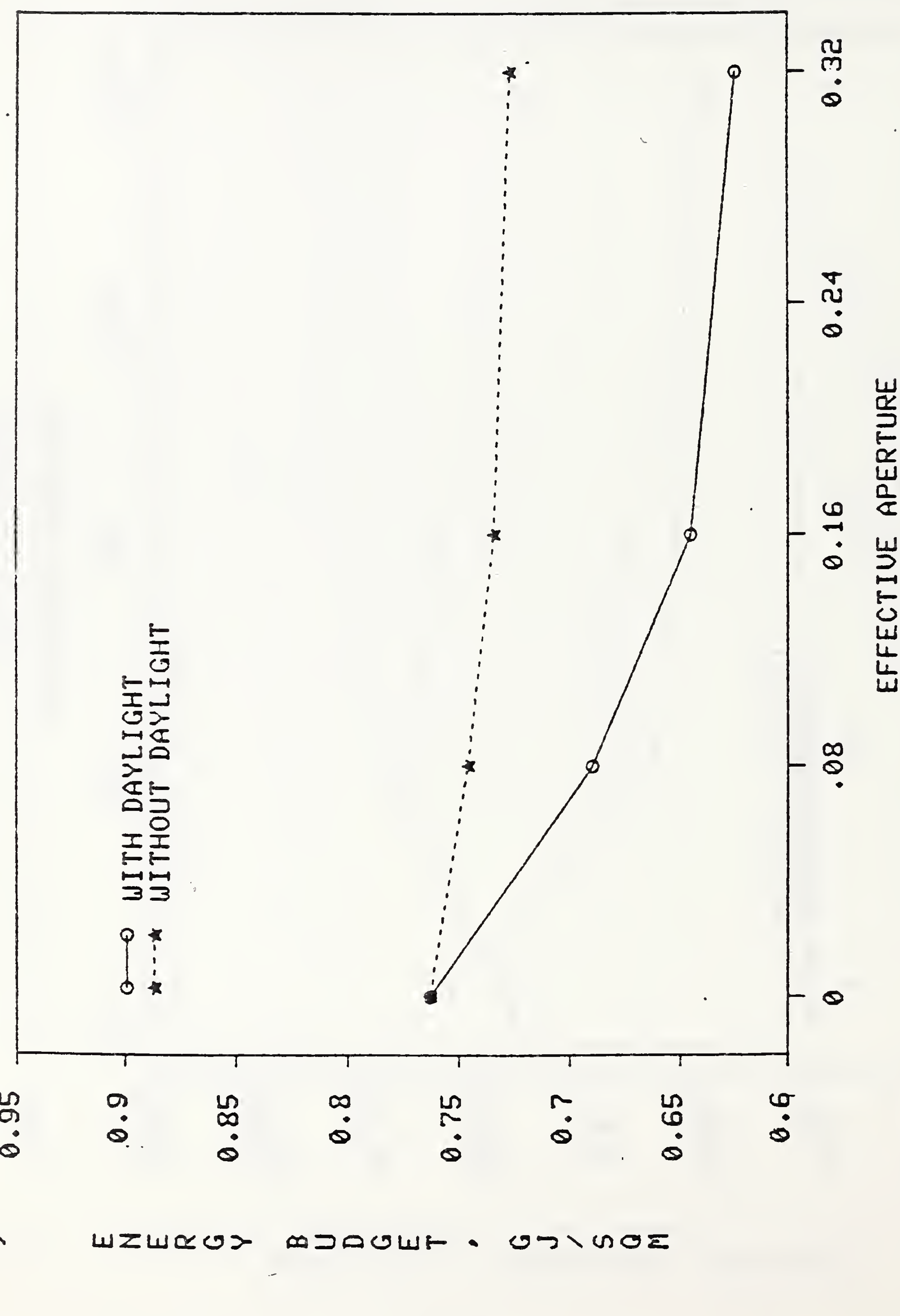


Figure 184. TOTAL ENERGY - NORTH WINDOW (Norfolk)
BRICK ATTACHED

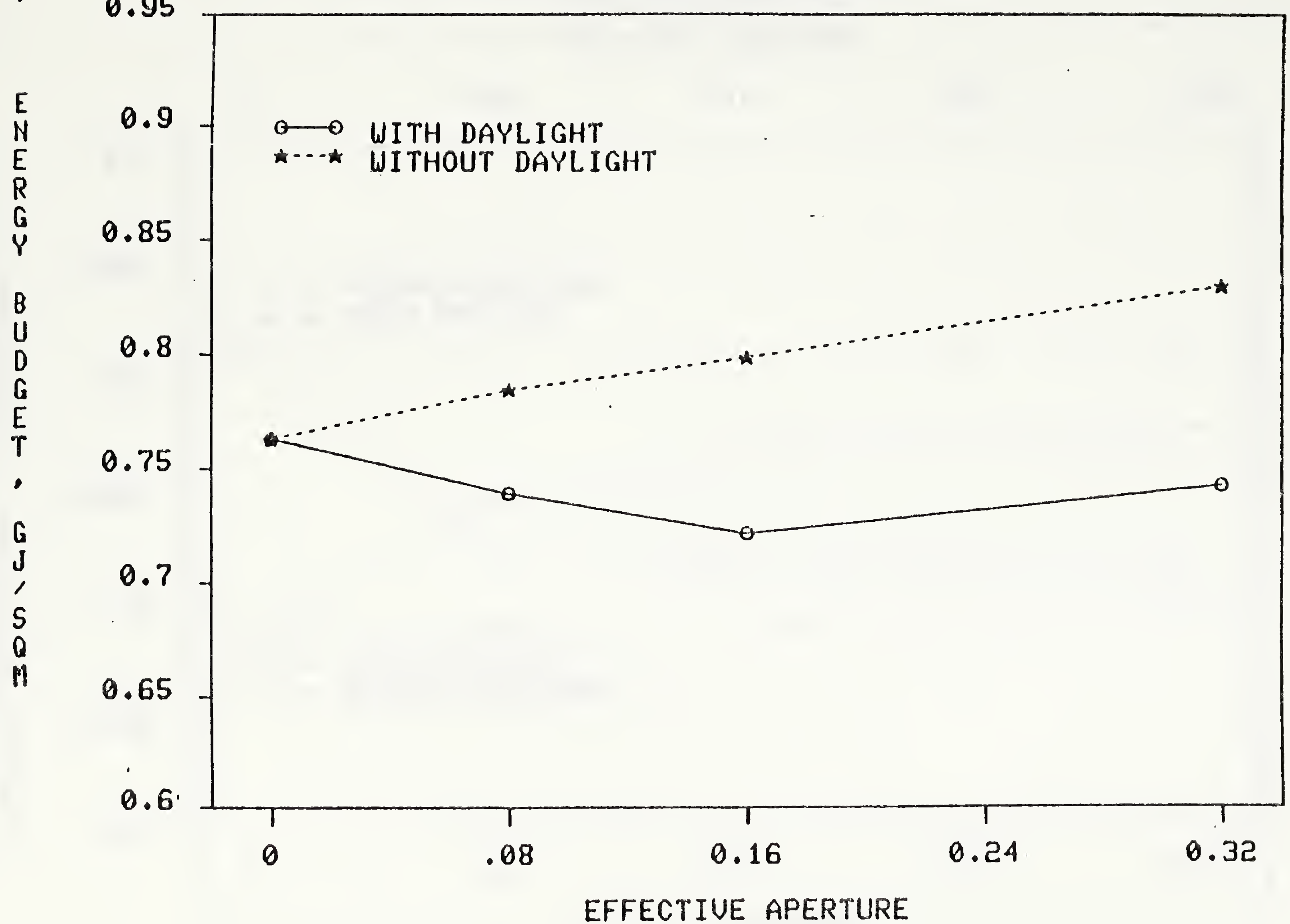


Figure 185. TOTAL ENERGY - SKYLIGHTS (Norfolk)
METAL FREESTANDING

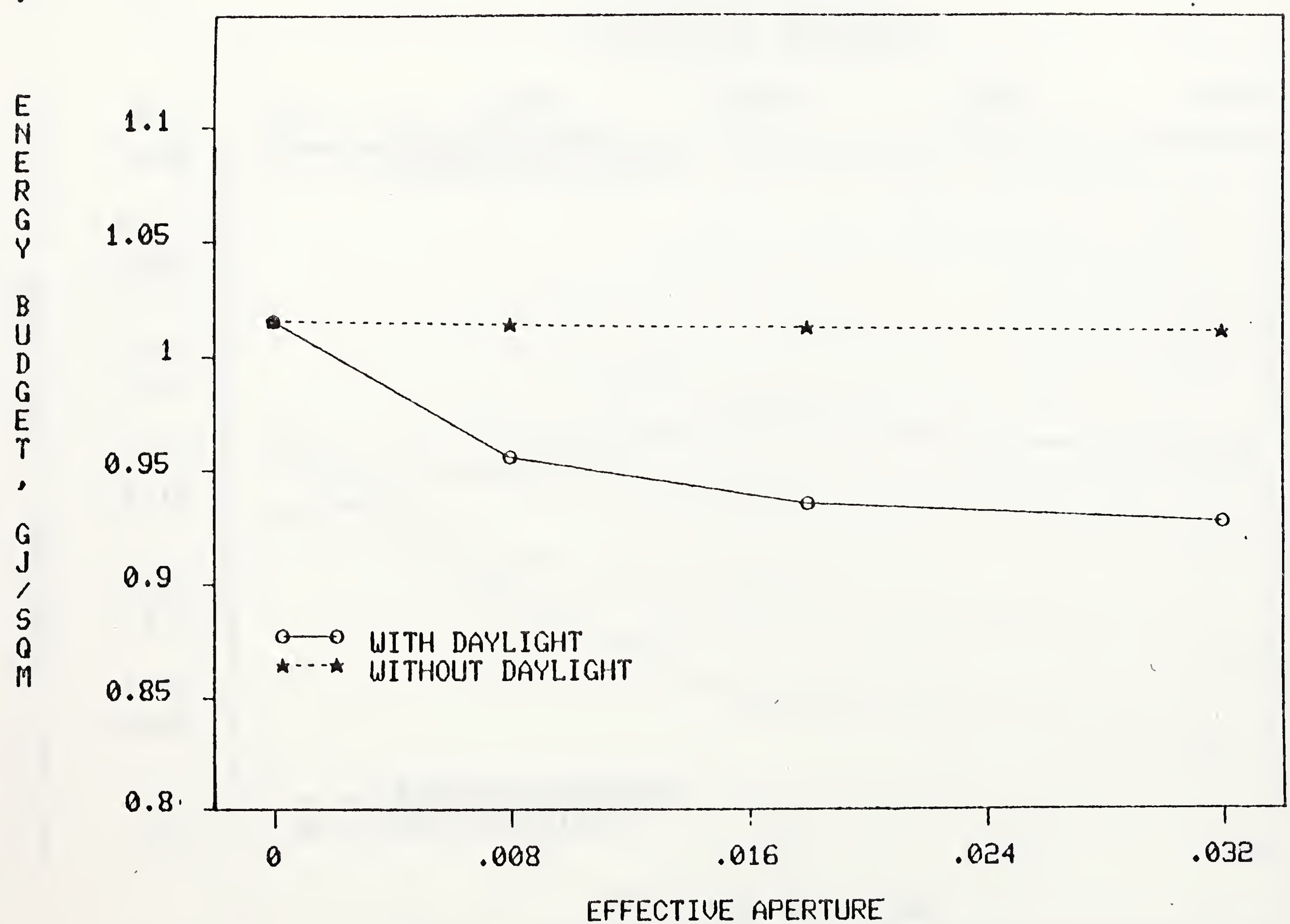


Figure 136. TOTAL ENERGY - SOUTH SAWTOOTH (Norfolk)
METAL FREESTANDING

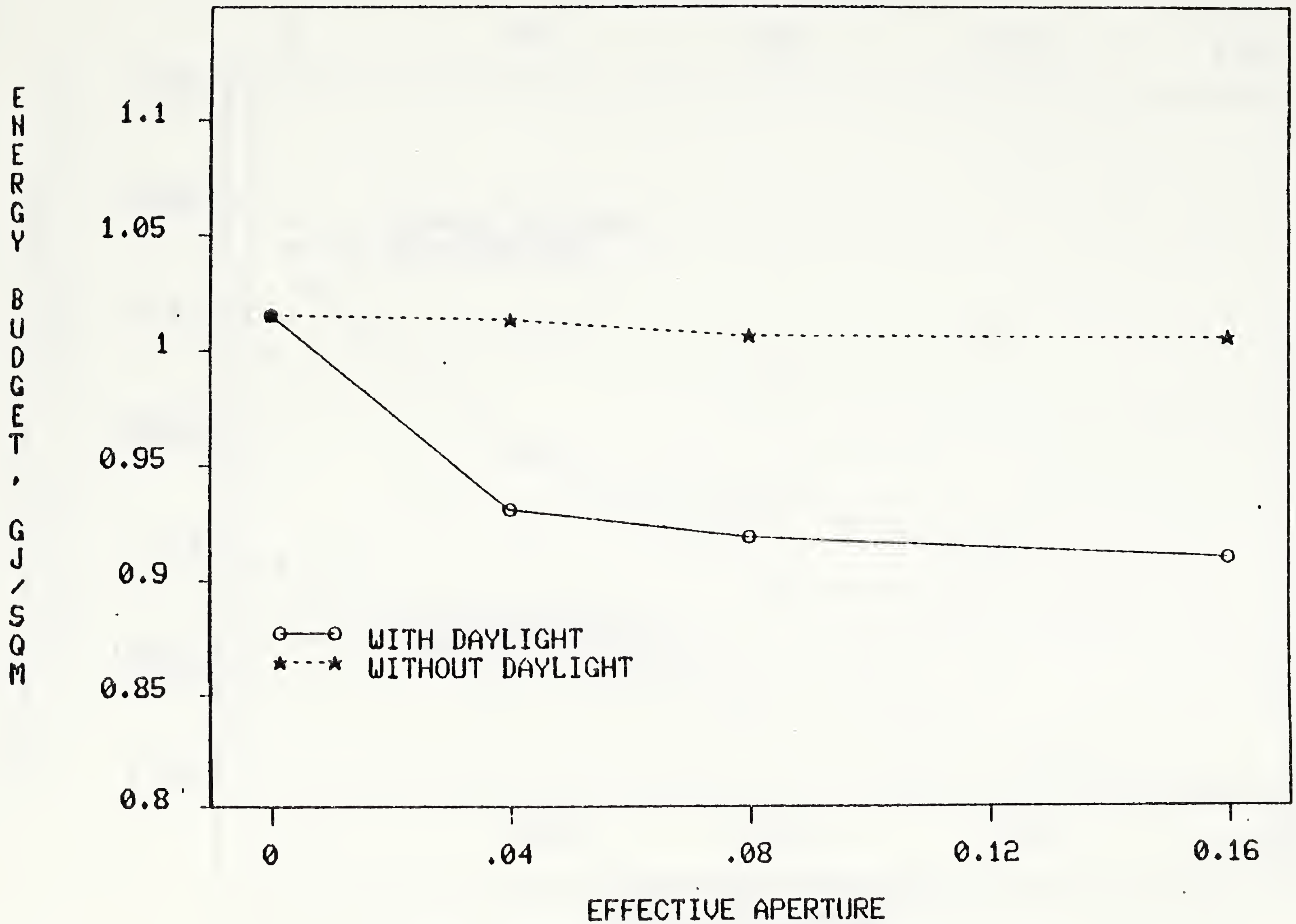


Figure 137. TOTAL ENERGY - NORTH SAWTOOTH (Norfolk)
METAL FREESTANDING

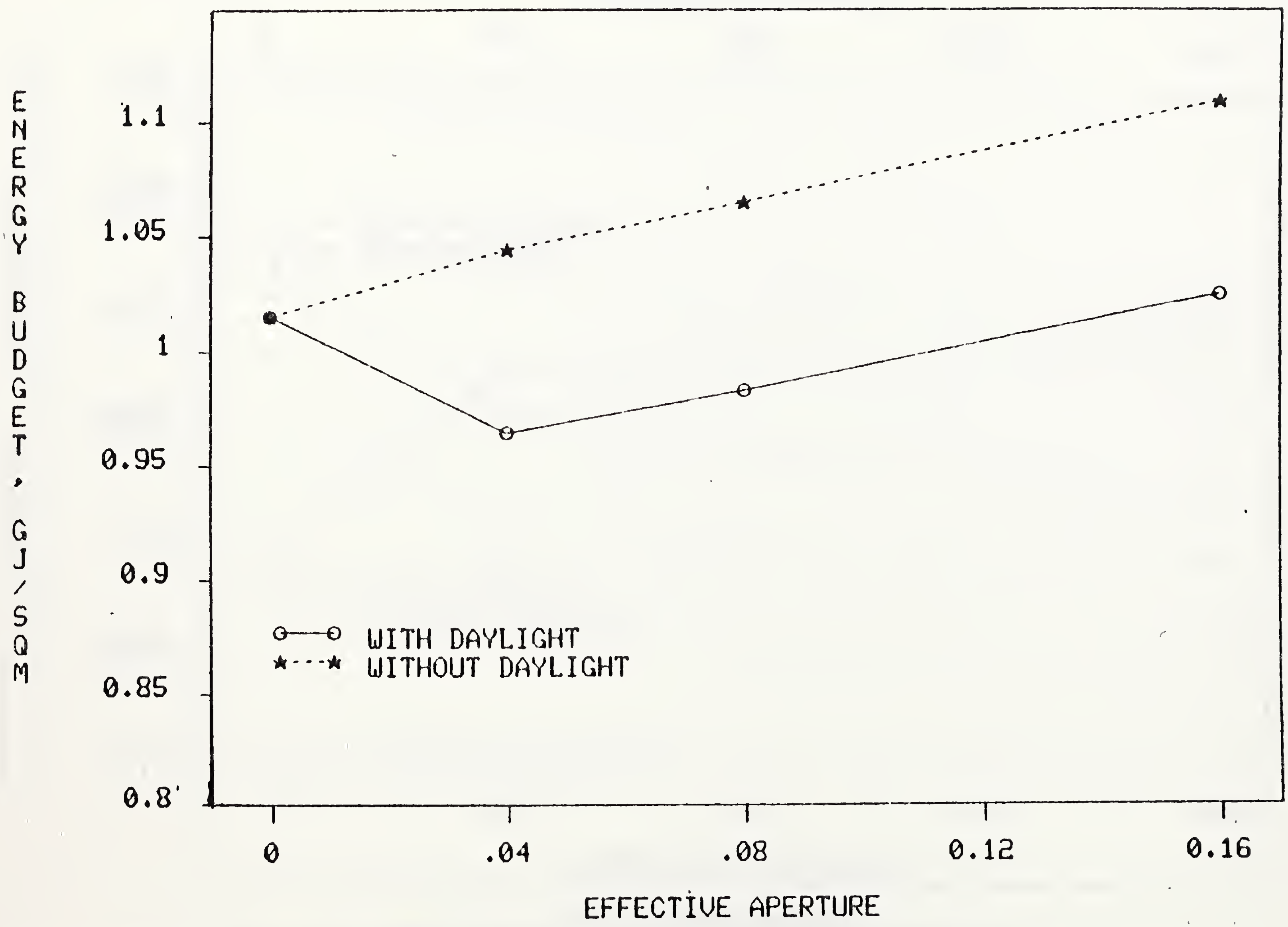


Figure 188. TOTAL ENERGY - SOUTH WINDOW (Norfolk)
METAL FREESTANDING

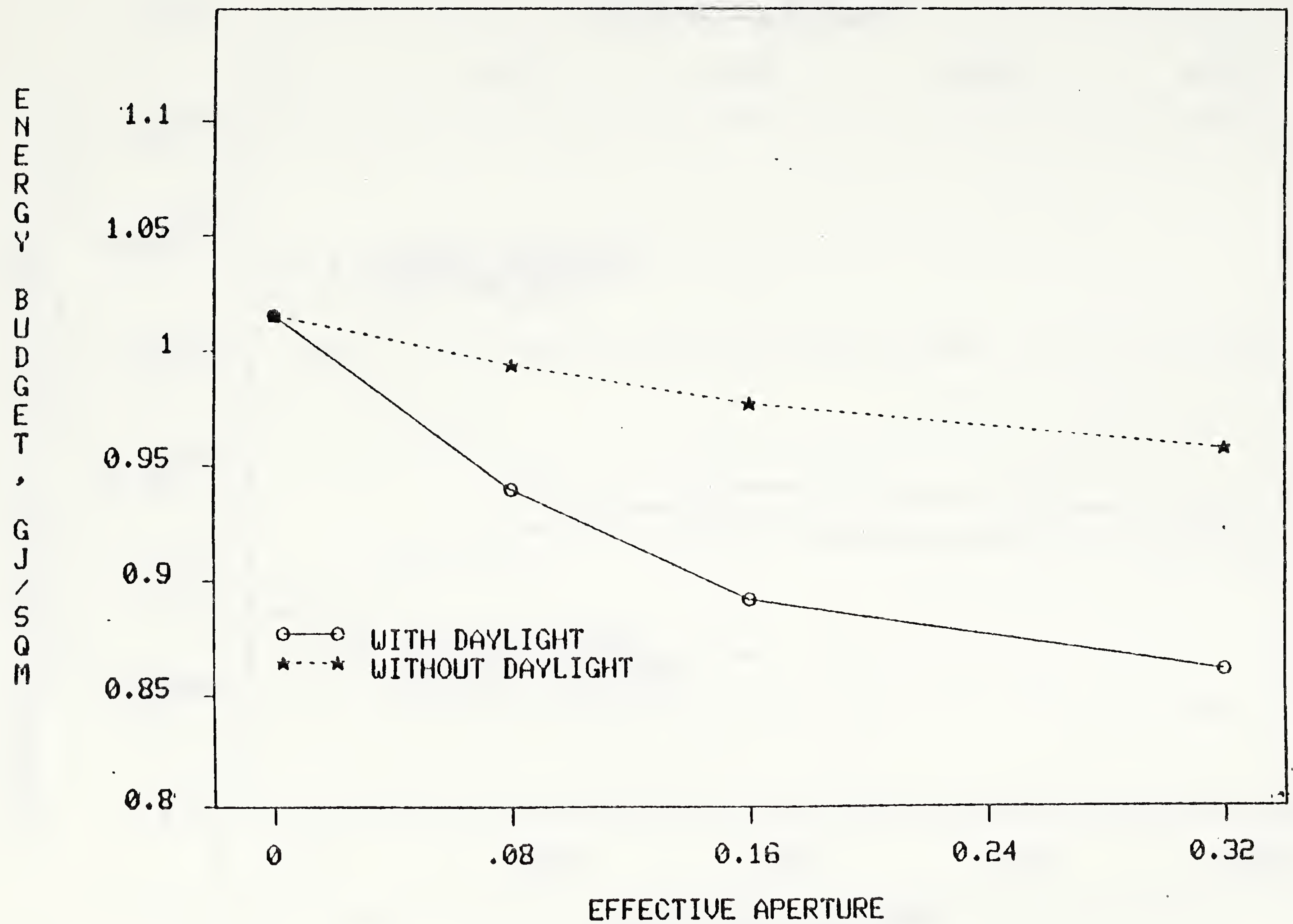


Figure 189. TOTAL ENERGY - NORTH WINDOW (Norfolk)
METAL FREESTANDING

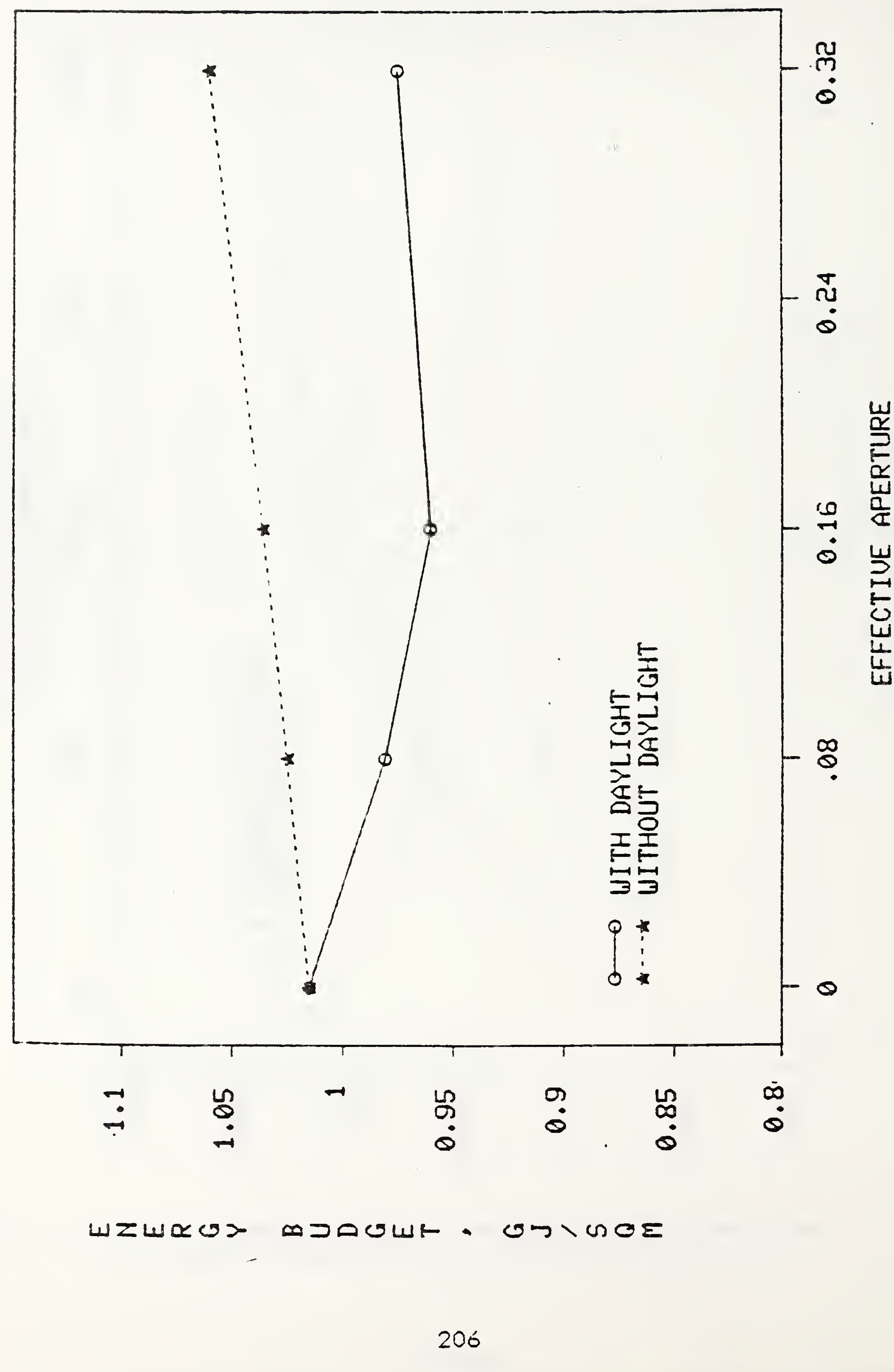


Figure 190. TOTAL ENERGY - SKYLIGHTS (Norfolk)
METAL ATTACHED

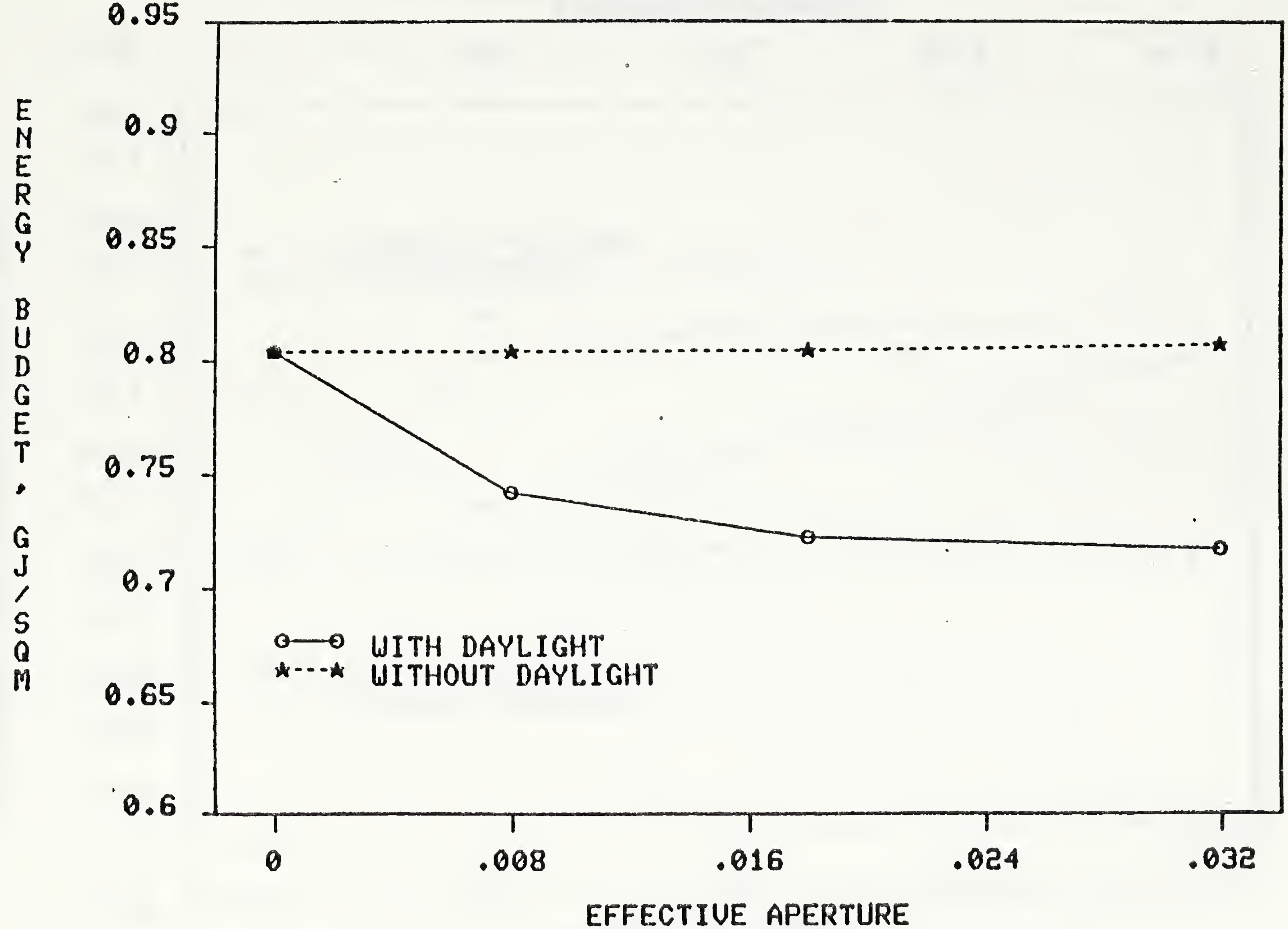


Figure 191. TOTAL ENERGY - SOUTH SAWTOOTH (Norfolk) METAL ATTACHED

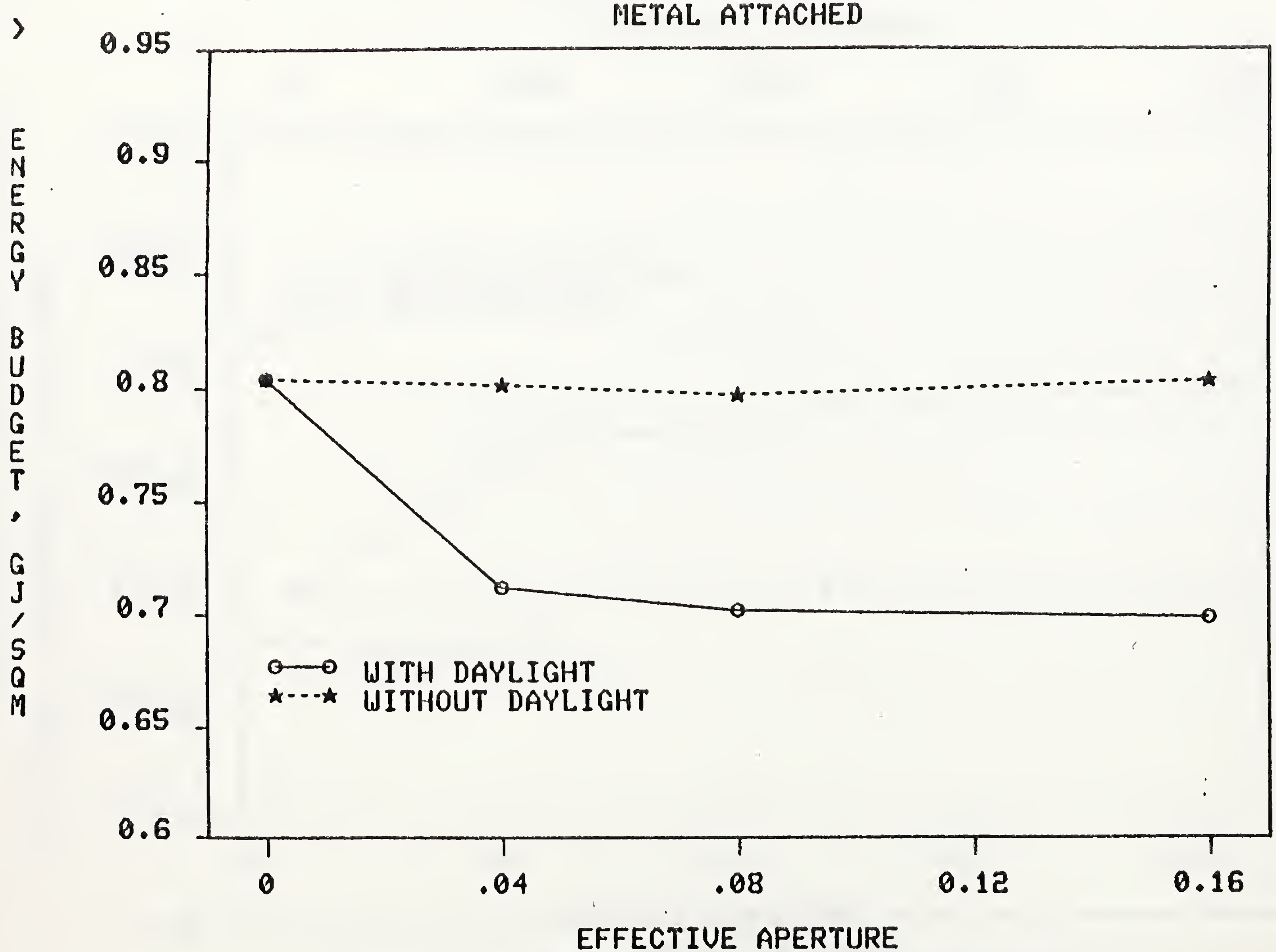


Figure 192. TOTAL ENERGY - NORTH SAWTOOTH (Norfolk)
METAL ATTACHED

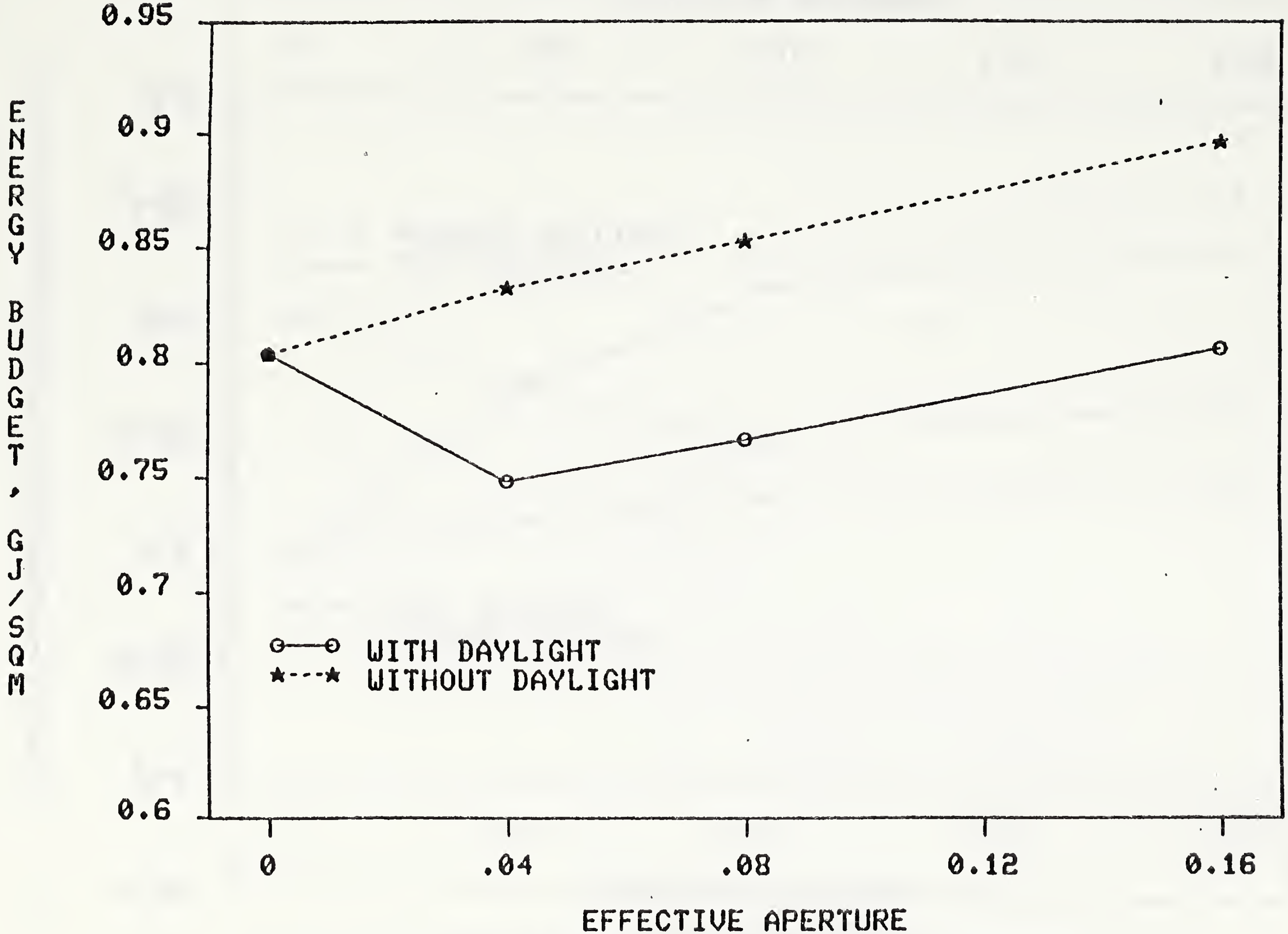


Figure 193. TOTAL ENERGY - SOUTH WINDOW (Norfolk)
METAL ATTACHED

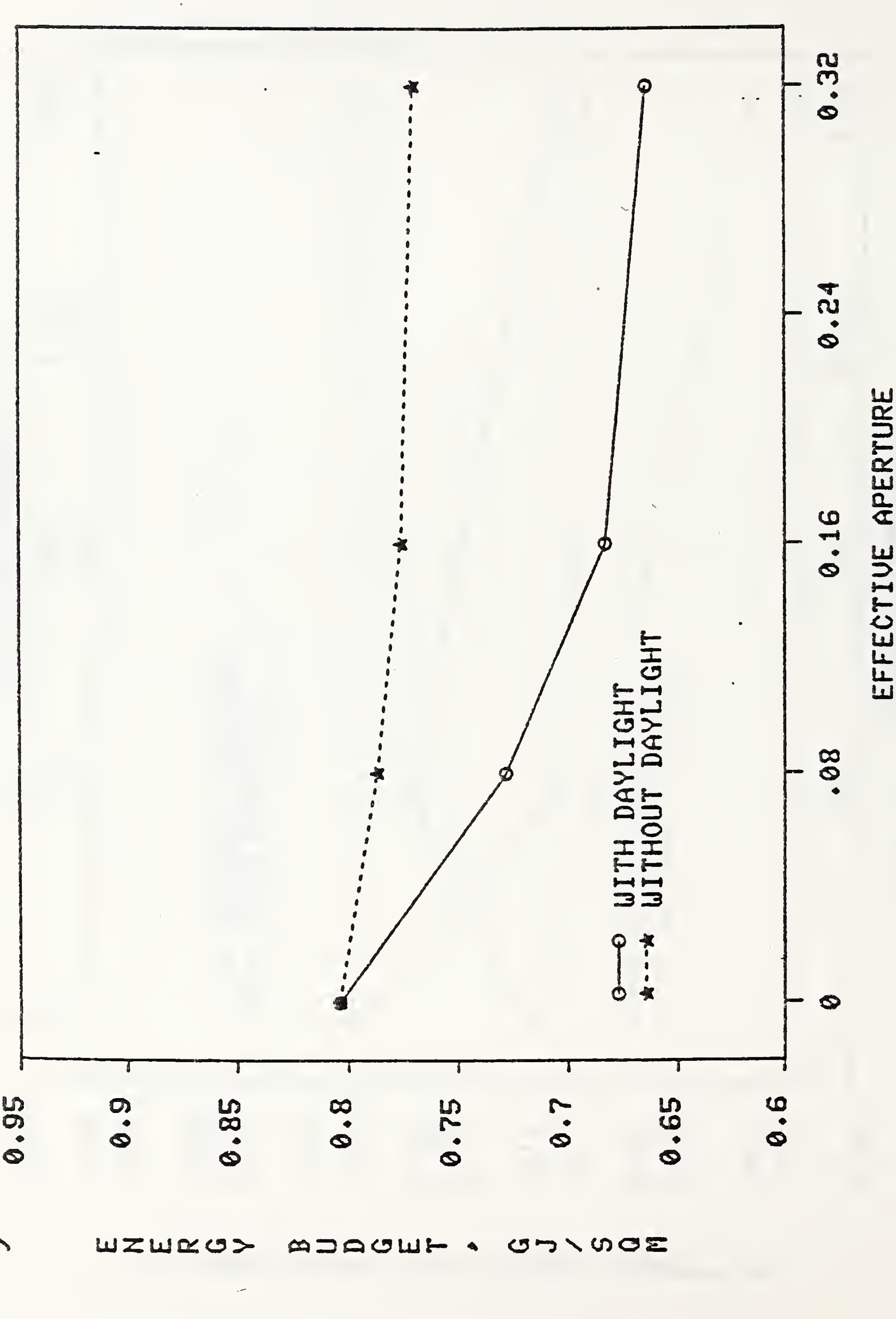


Figure 194. TOTAL ENERGY - NORTH WINDOW (Norfolk)
METAL ATTACHED

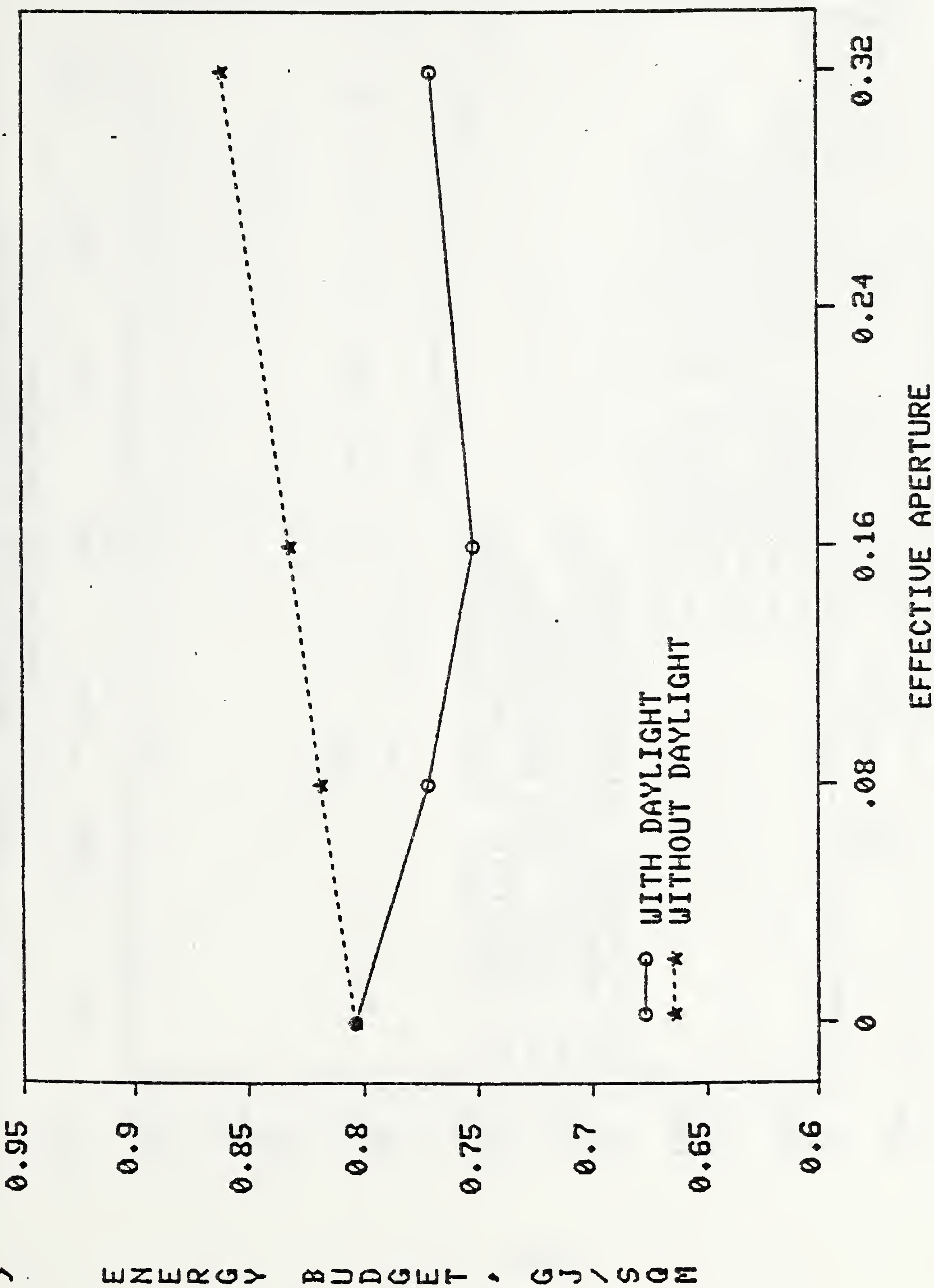


Figure 195. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
SKYLIGHTS, BRICK FREESTANDING

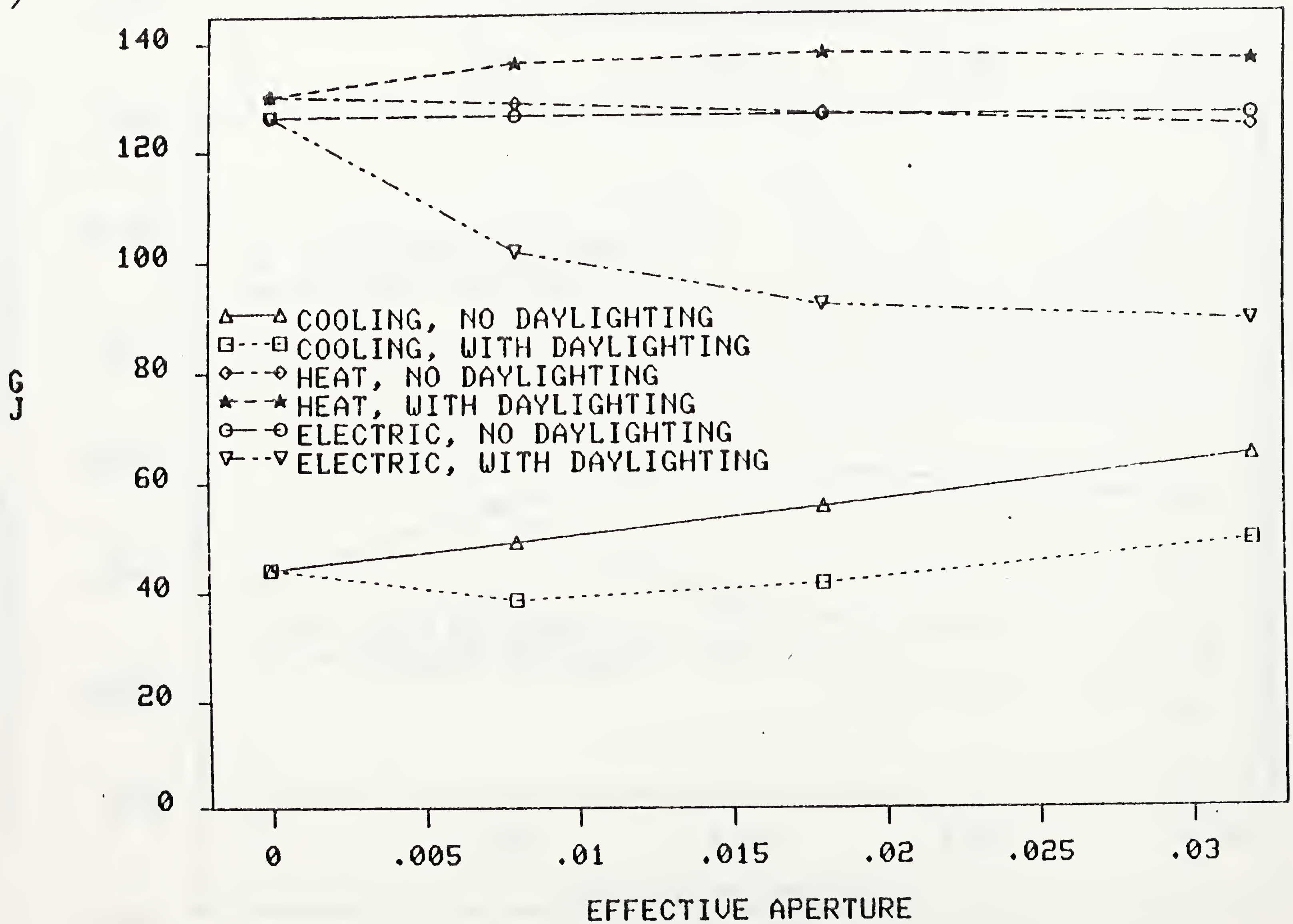


Figure 196. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
SOUTH SAWTOOTH, BRICK FREESTANDING

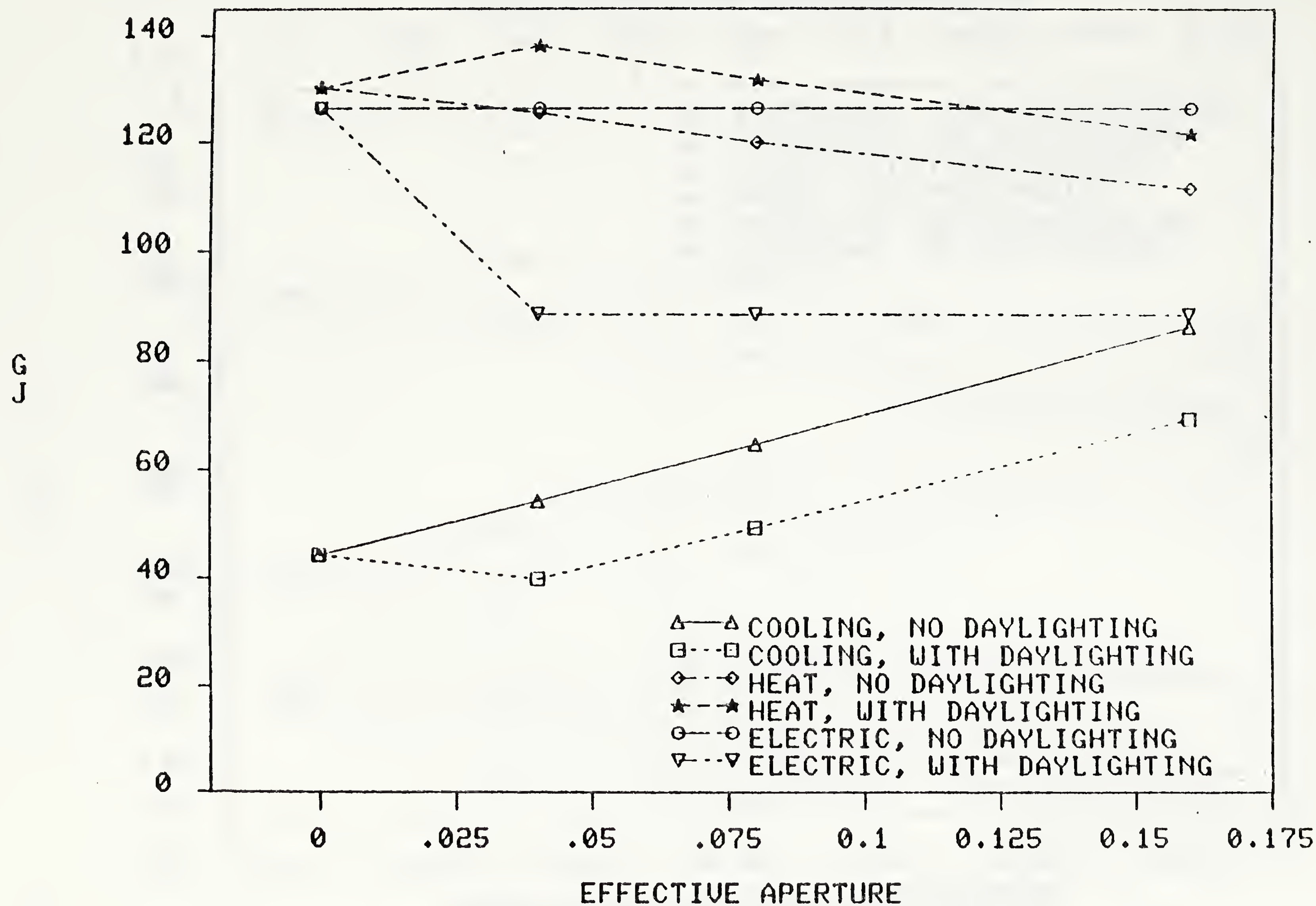


Figure 197. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
NORTH SAWTOOTH, BRICK FREESTANDING

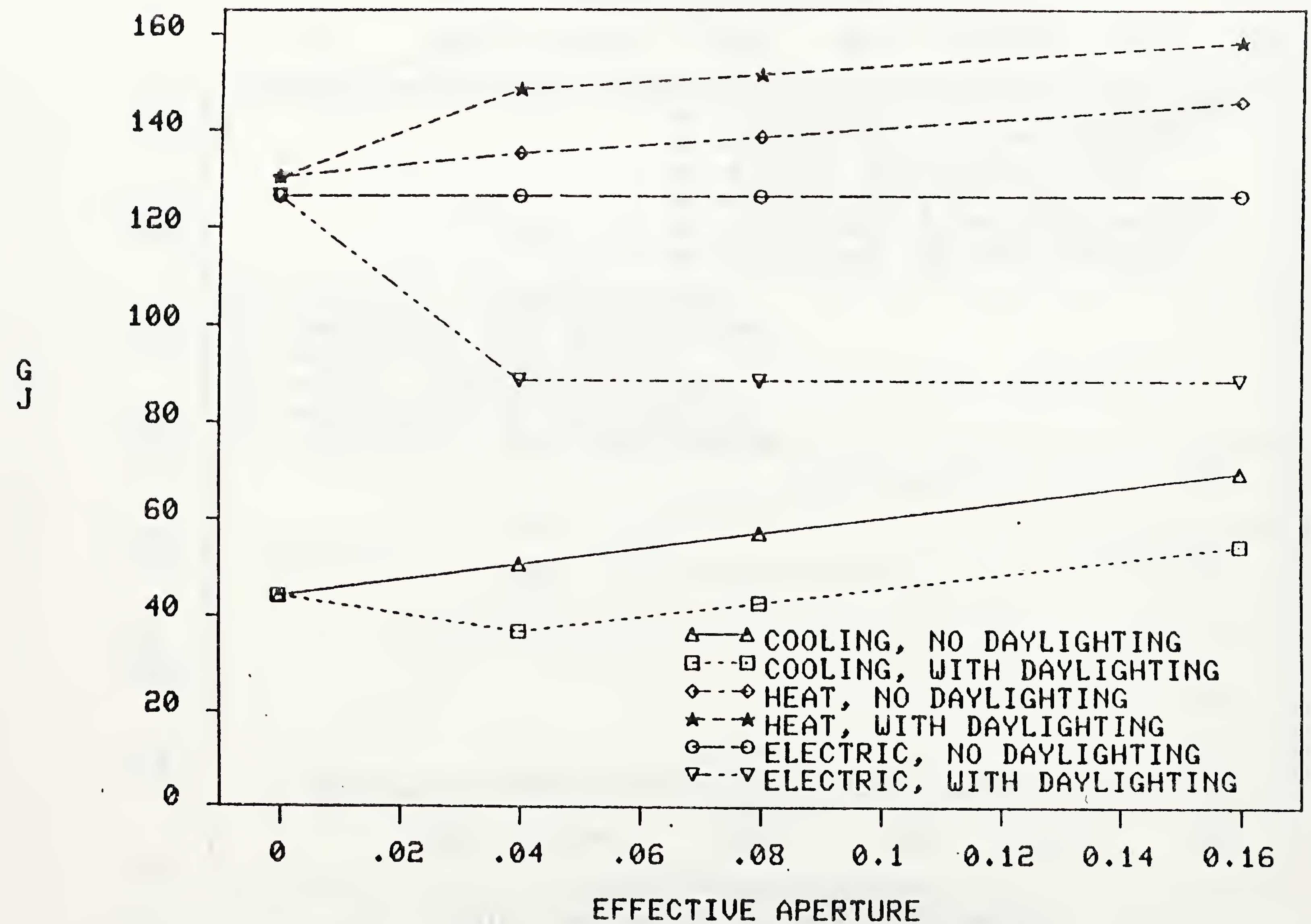


Figure 198. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
SOUTH WINDOW, BRICK FREESTANDING

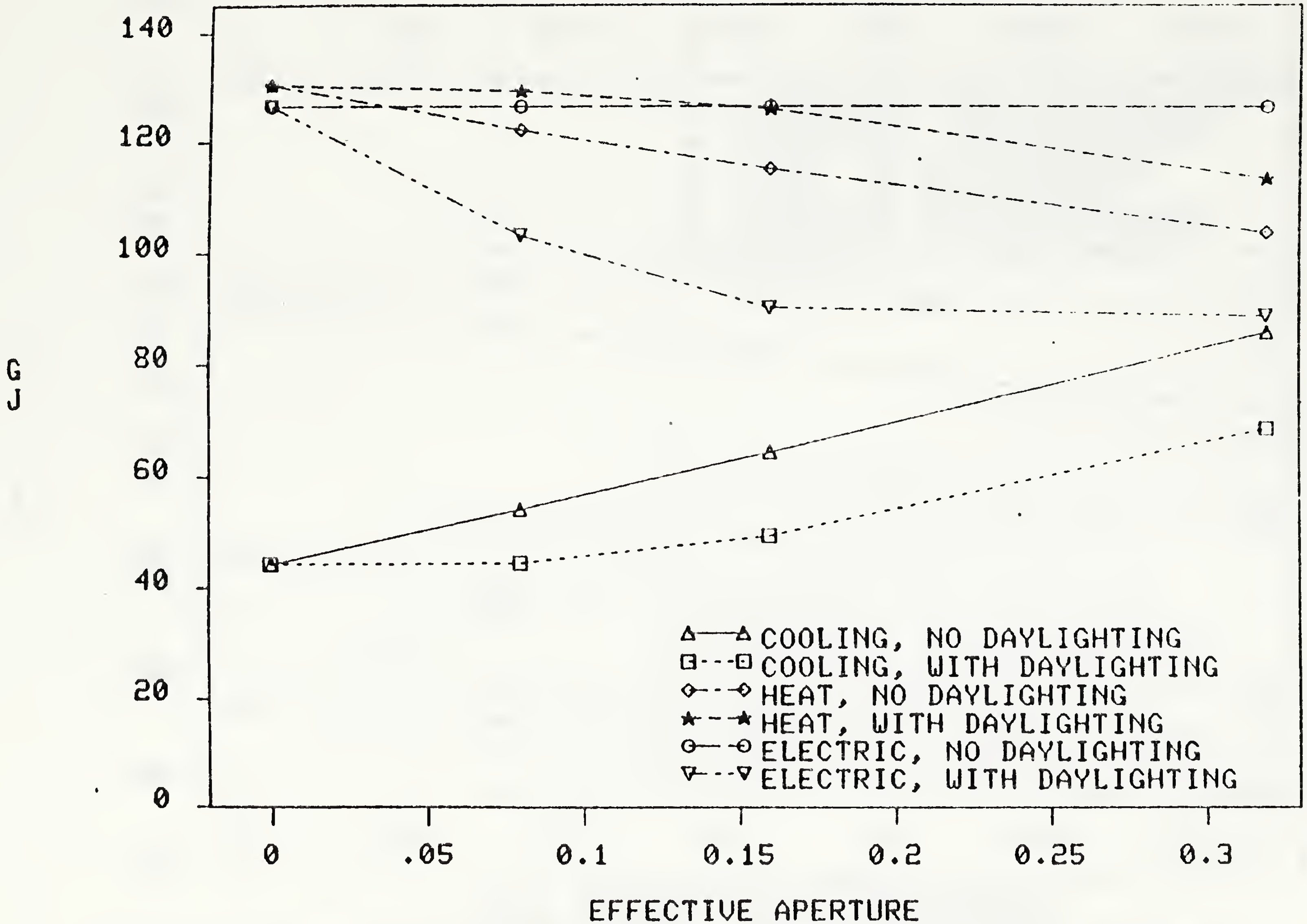


Figure 199. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk) NORTH WINDOW, BRICK FREESTANDING

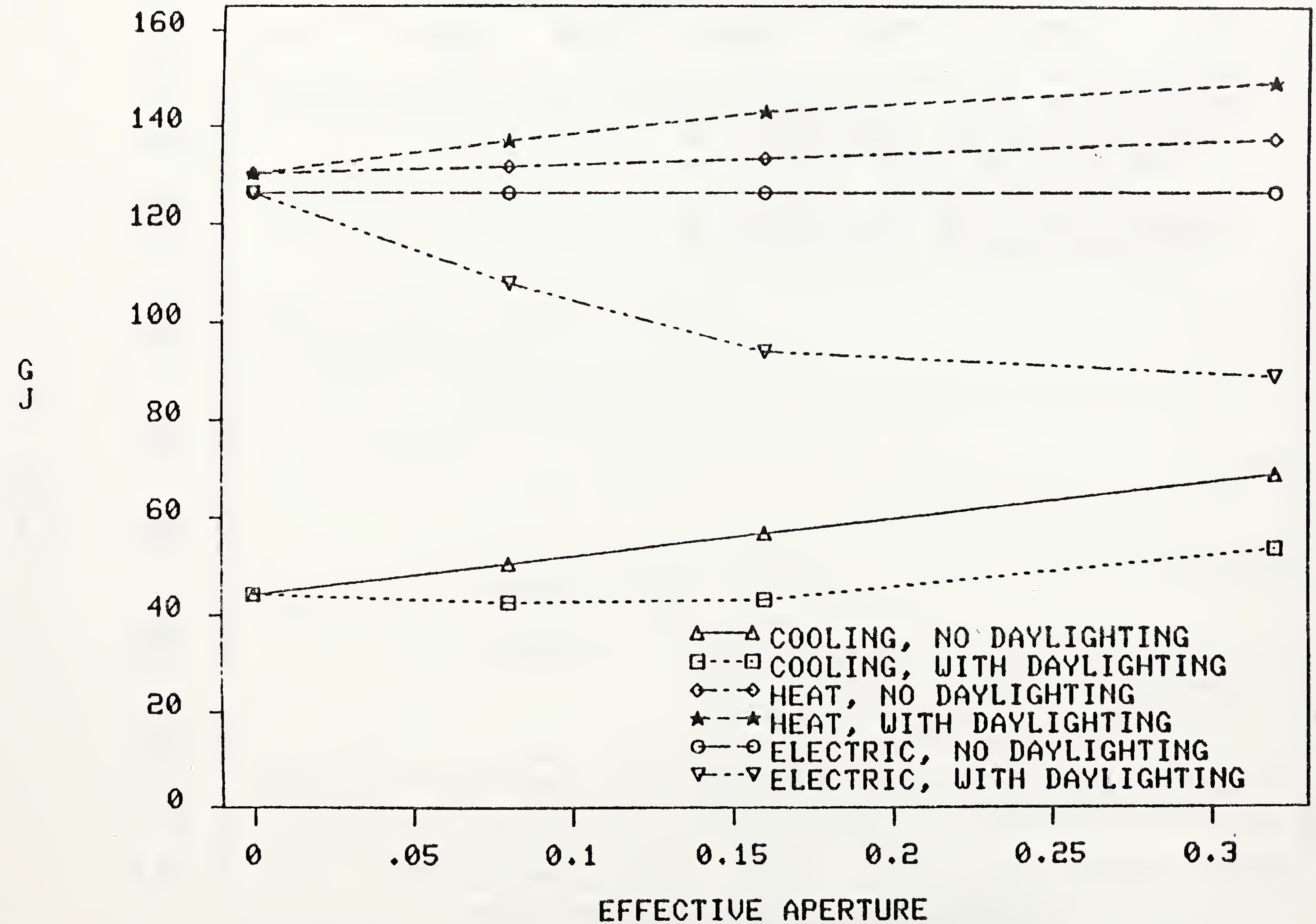


Figure 200. ANNUAL COOLING, HEATING AND ELECTRIC LOADS (Norfolk) SKYLIGHTS, BRICK ATTACHED

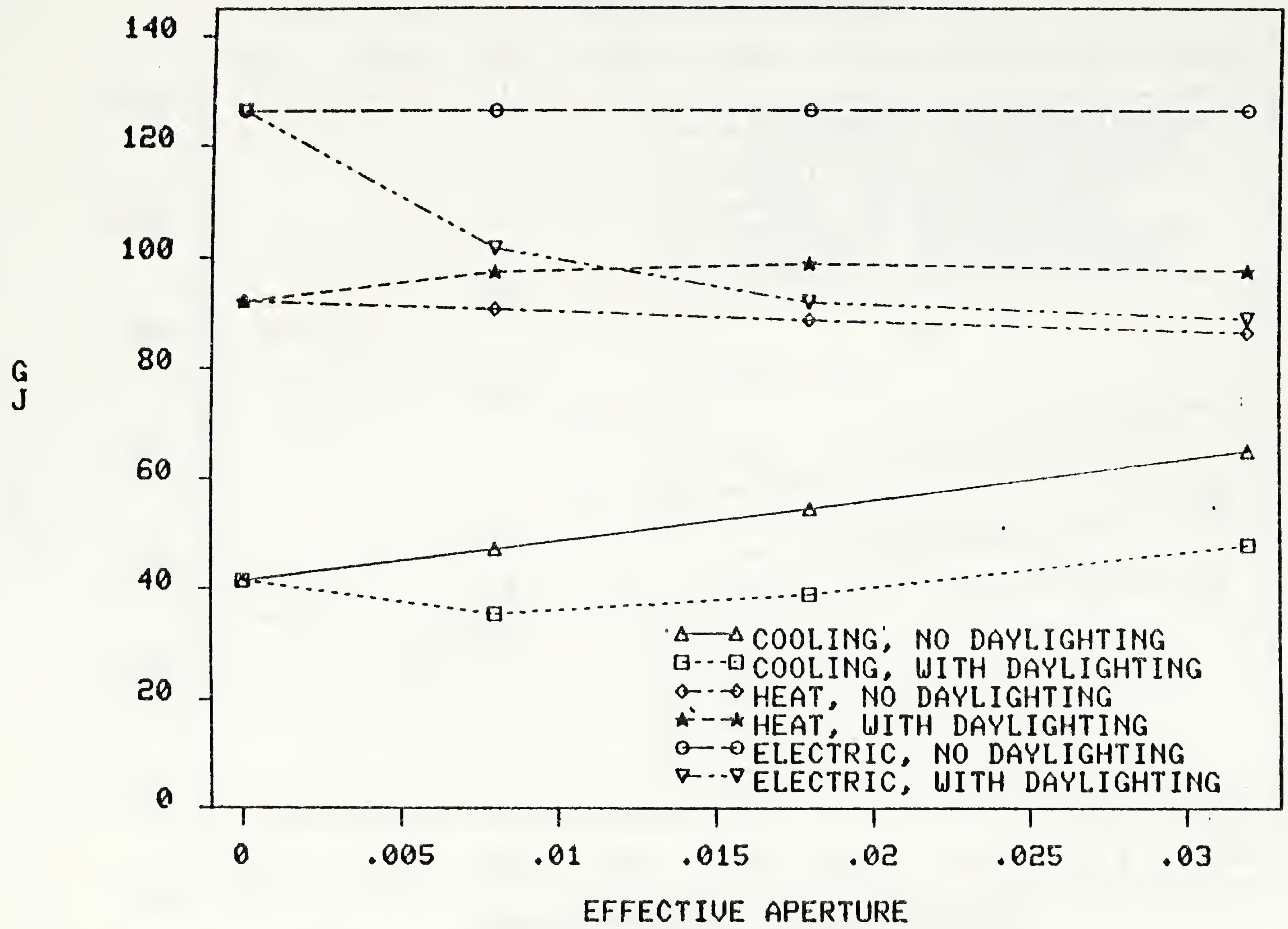


Figure 201. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
SOUTH SAWTOOTH, BRICK.ATTACHED

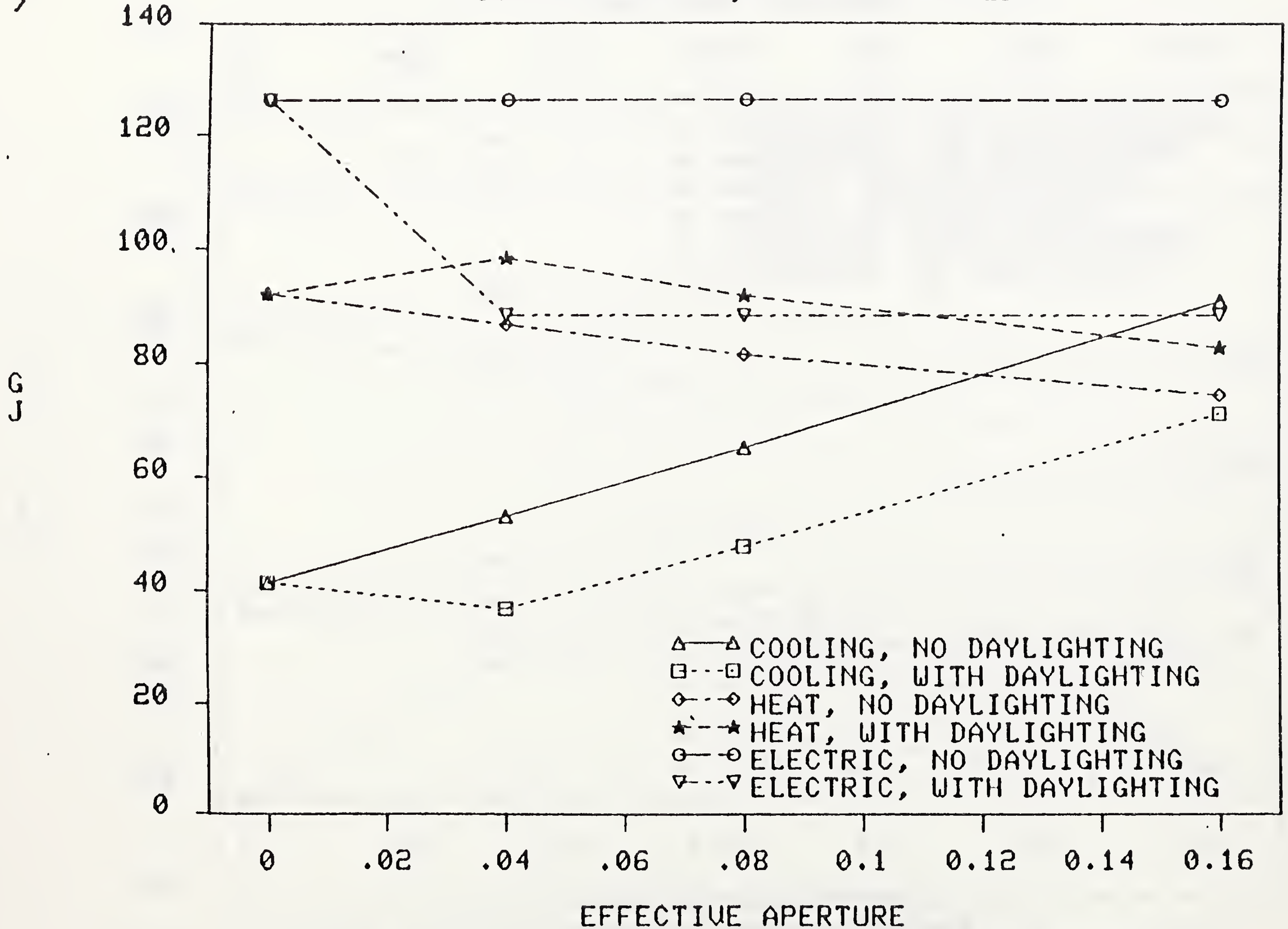


Figure 202. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk) NORTH SAWTOOTH, BRICK ATTACHED

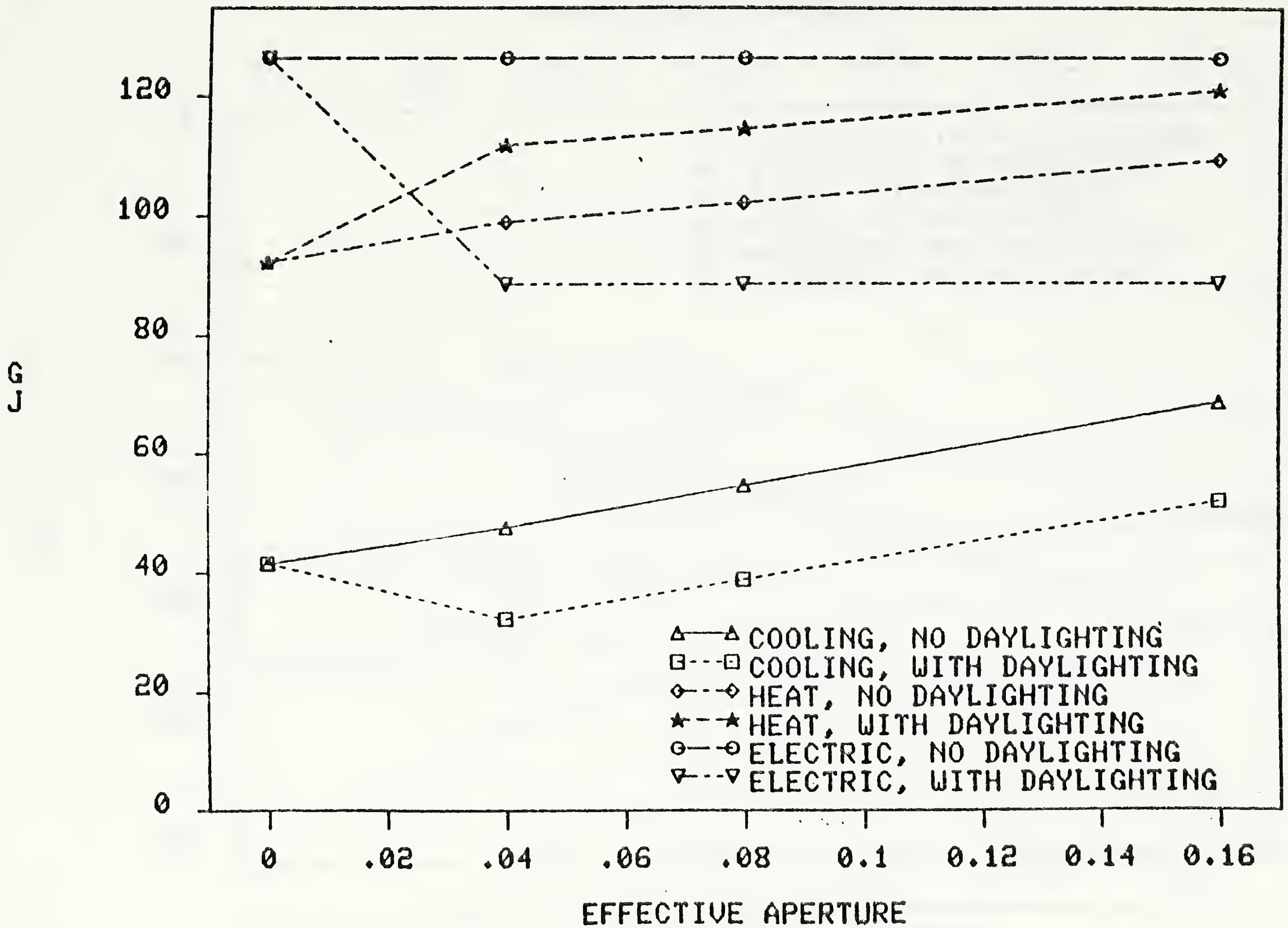


Figure 203. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
SOUTH WINDOW, BRICK ATTACHED

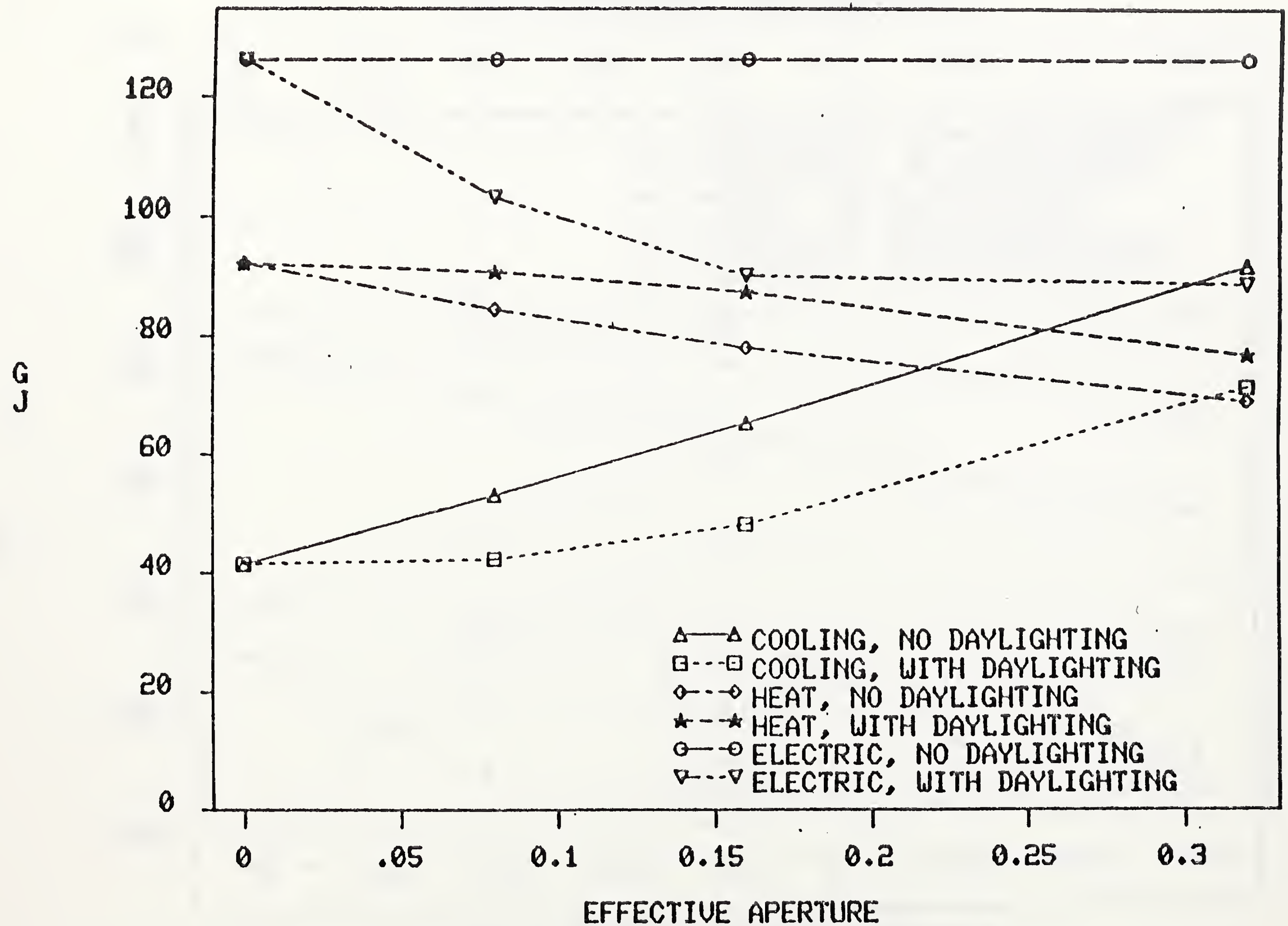


Figure 204. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
NORTH WINDOW, BRICK ATTACHED

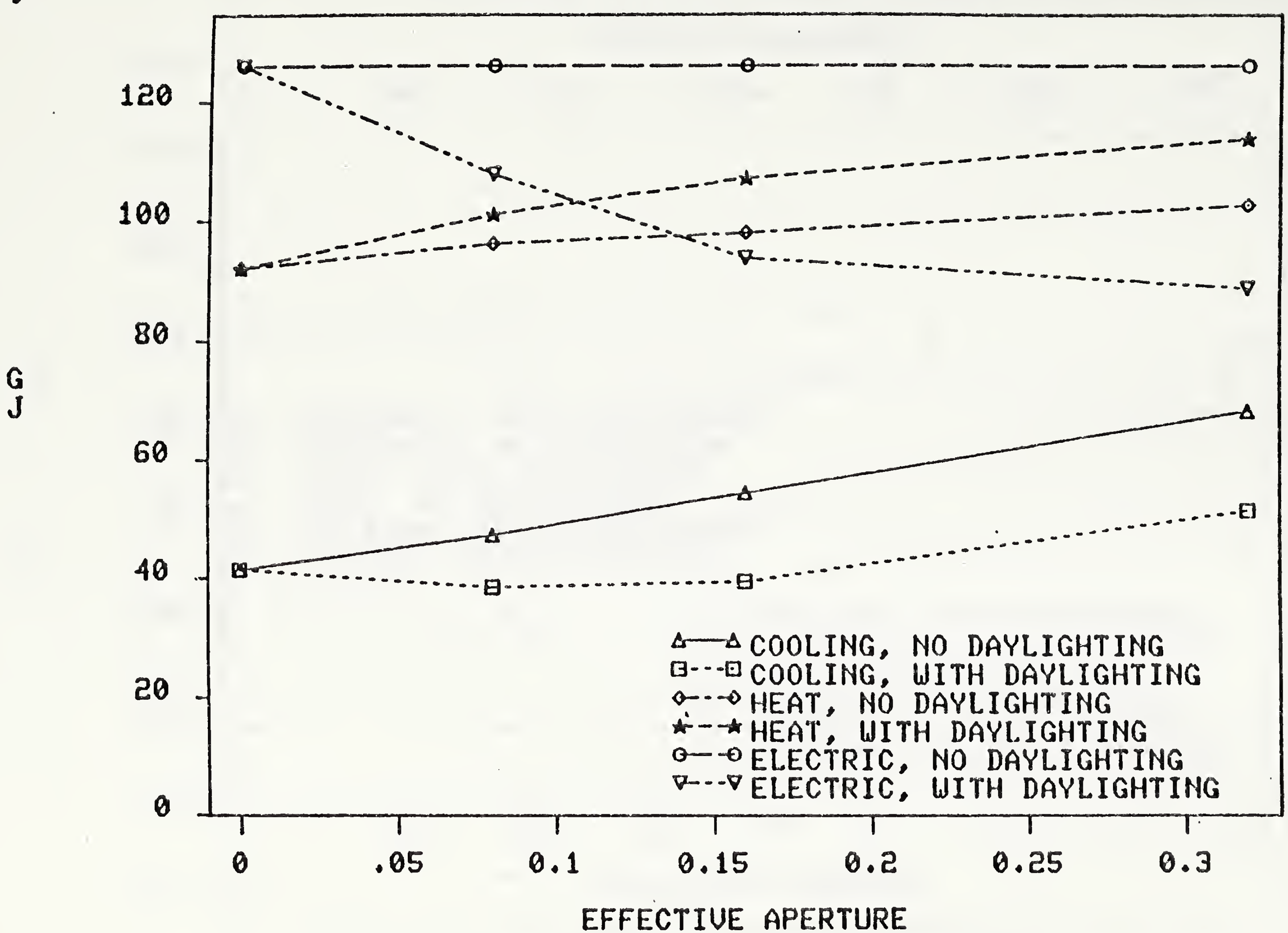


Figure 205. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk) SKYLIGHTS, METAL FREESTANDING

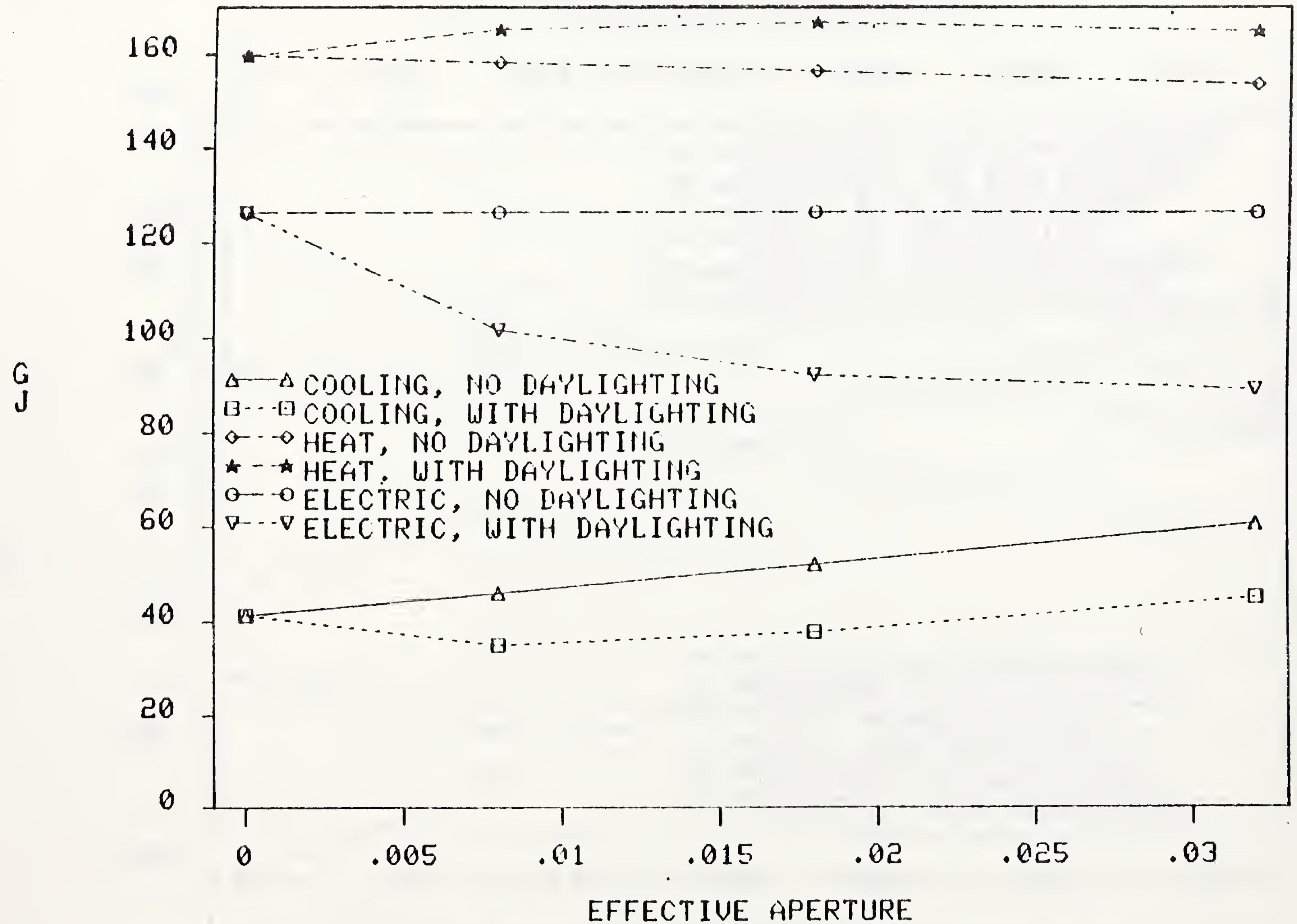


Figure 206. ANNUAL COOLING , HEATING AND ELECTPIC LOADS (Norfolk)
SOUTH SAWTOOTH, METAL FREESTANDING

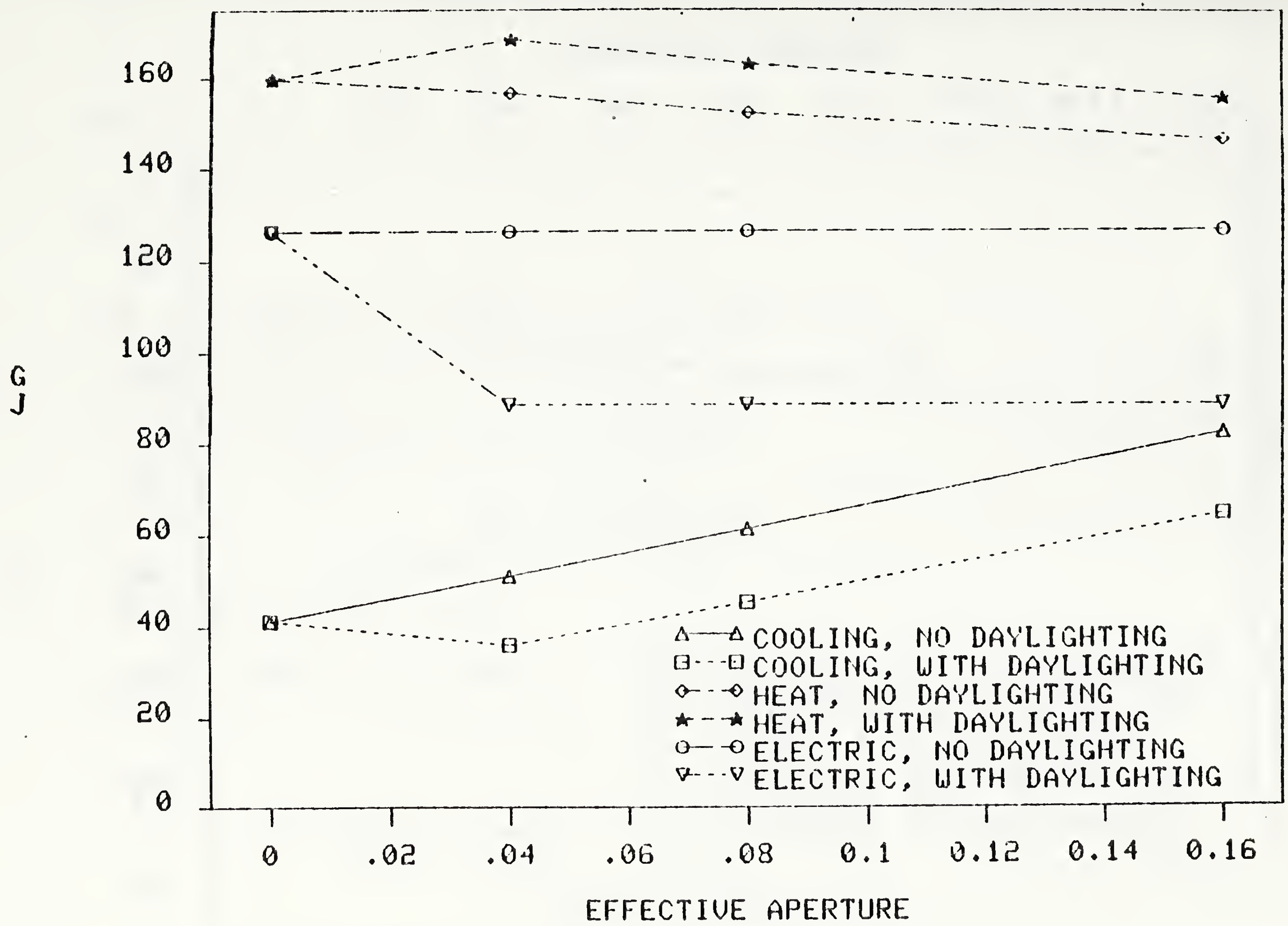


Figure 207. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
NORTH SAWTOOTH, METAL FREESTANDING

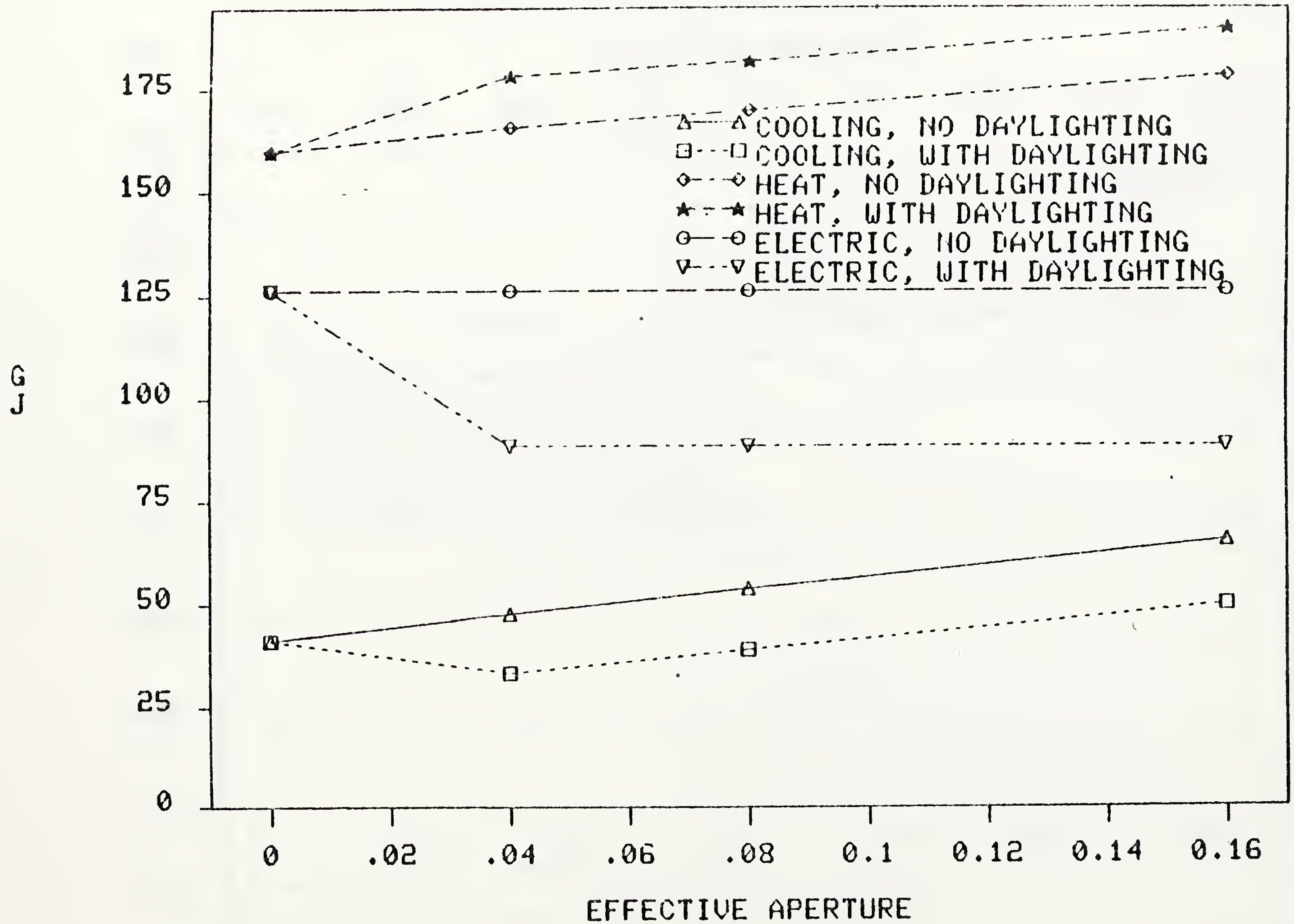


Figure 208. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
SOUTH WINDOW, METAL FREESTANDING

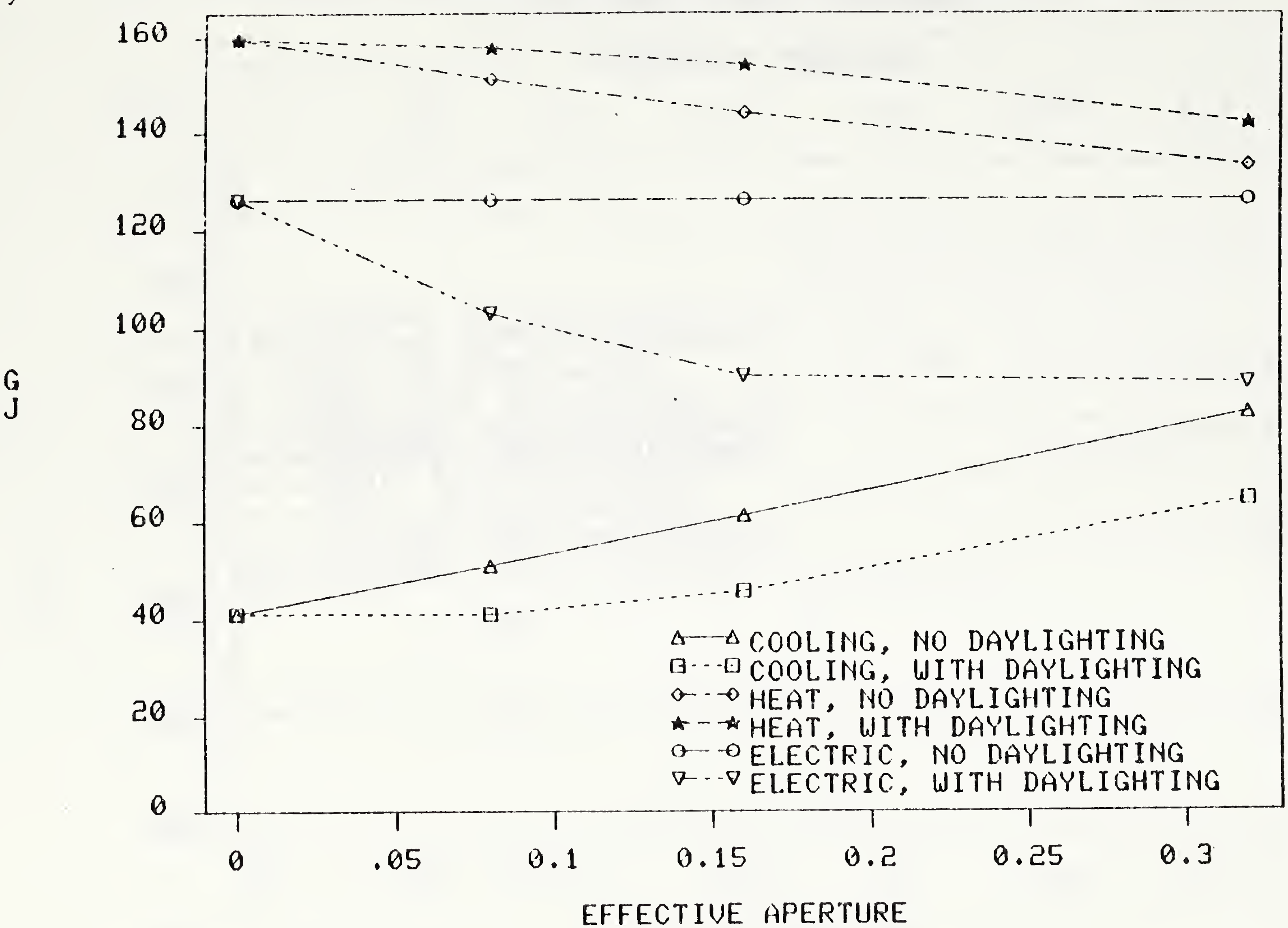


Figure 209. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
NORTH WINDOW, METAL FREESTANDING

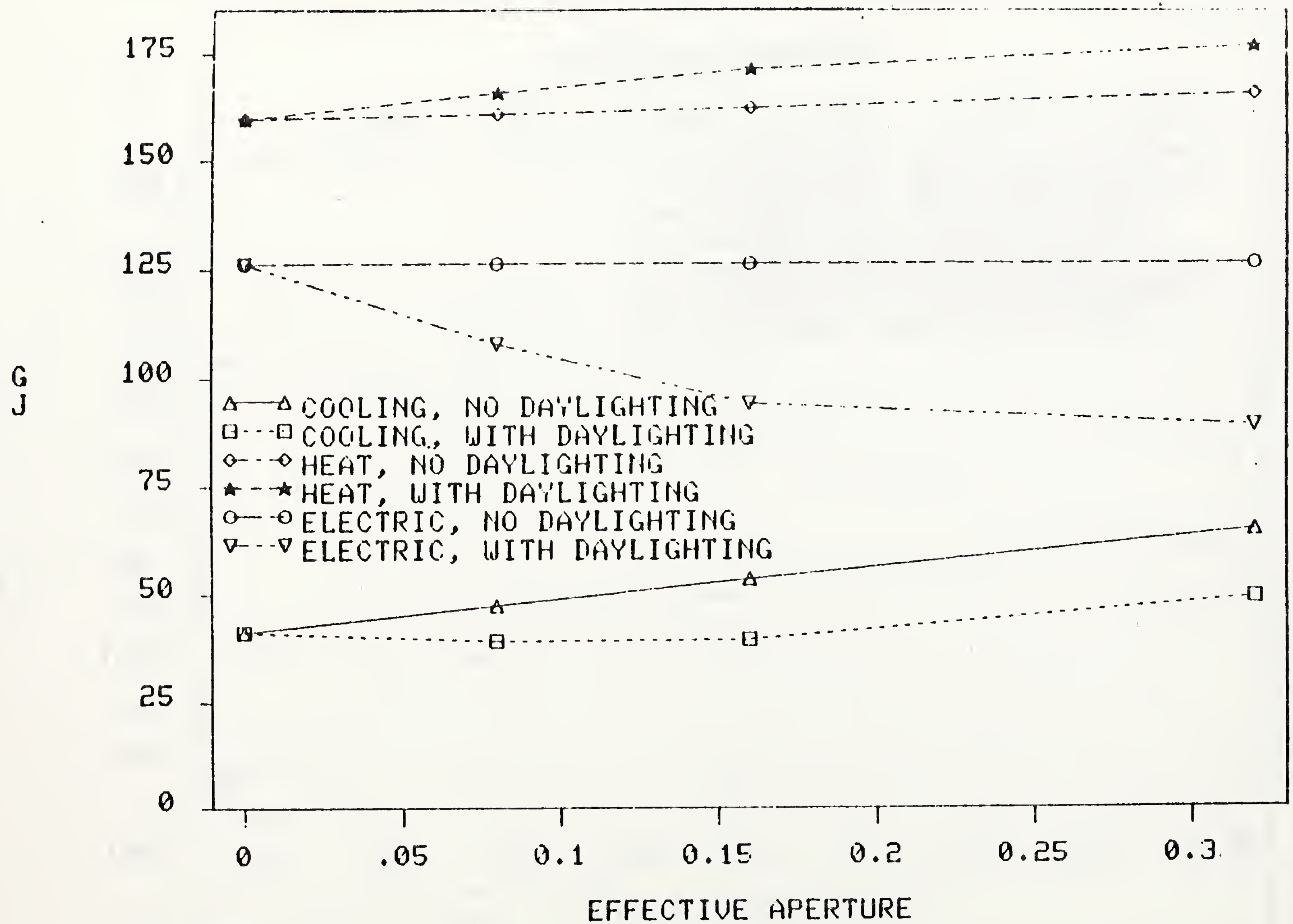


Figure 210. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
SKYLIGHTS, METAL ATTACHED

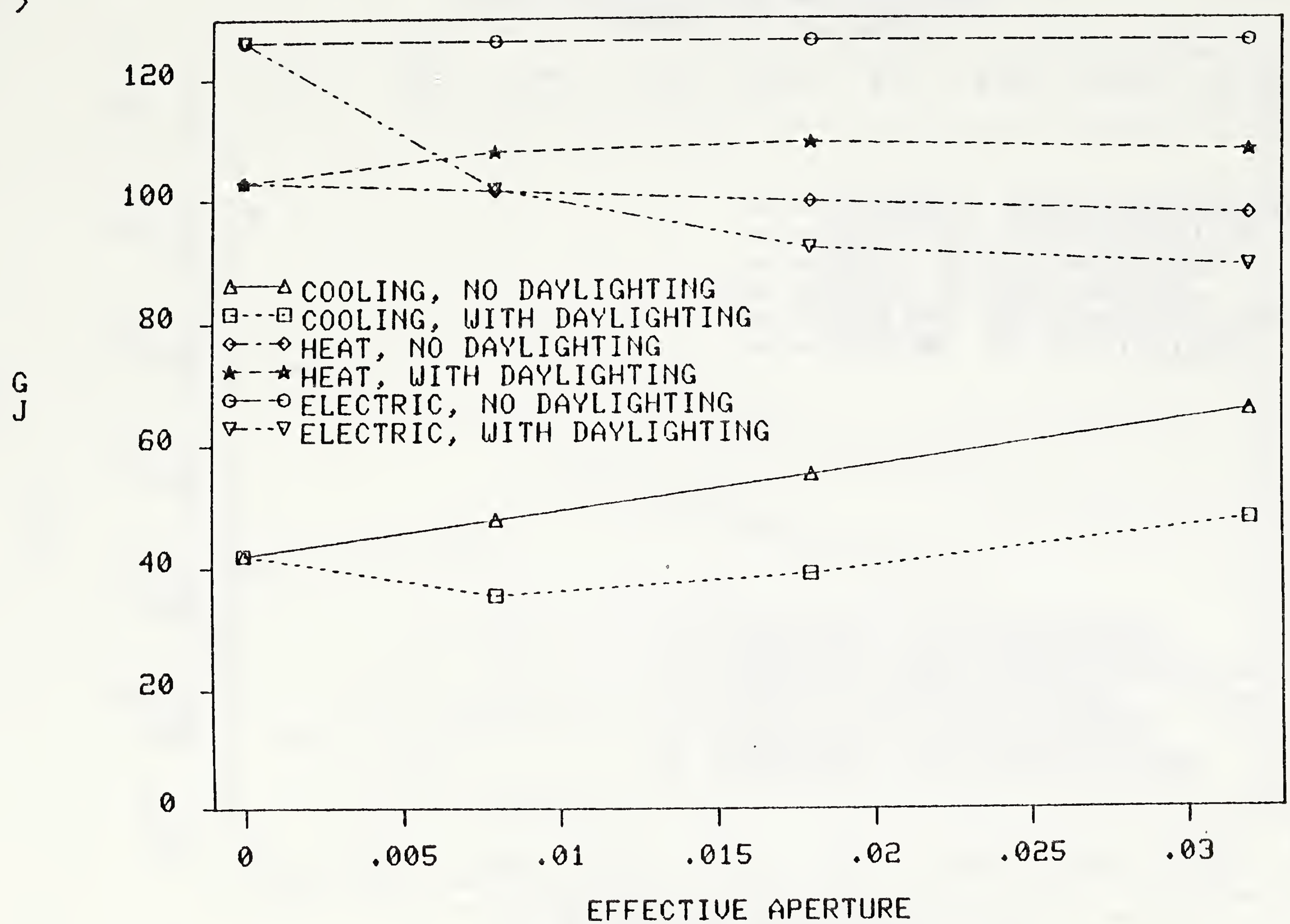


Figure 211. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
SOUTH SAWTOOTH, METAL ATTACHED

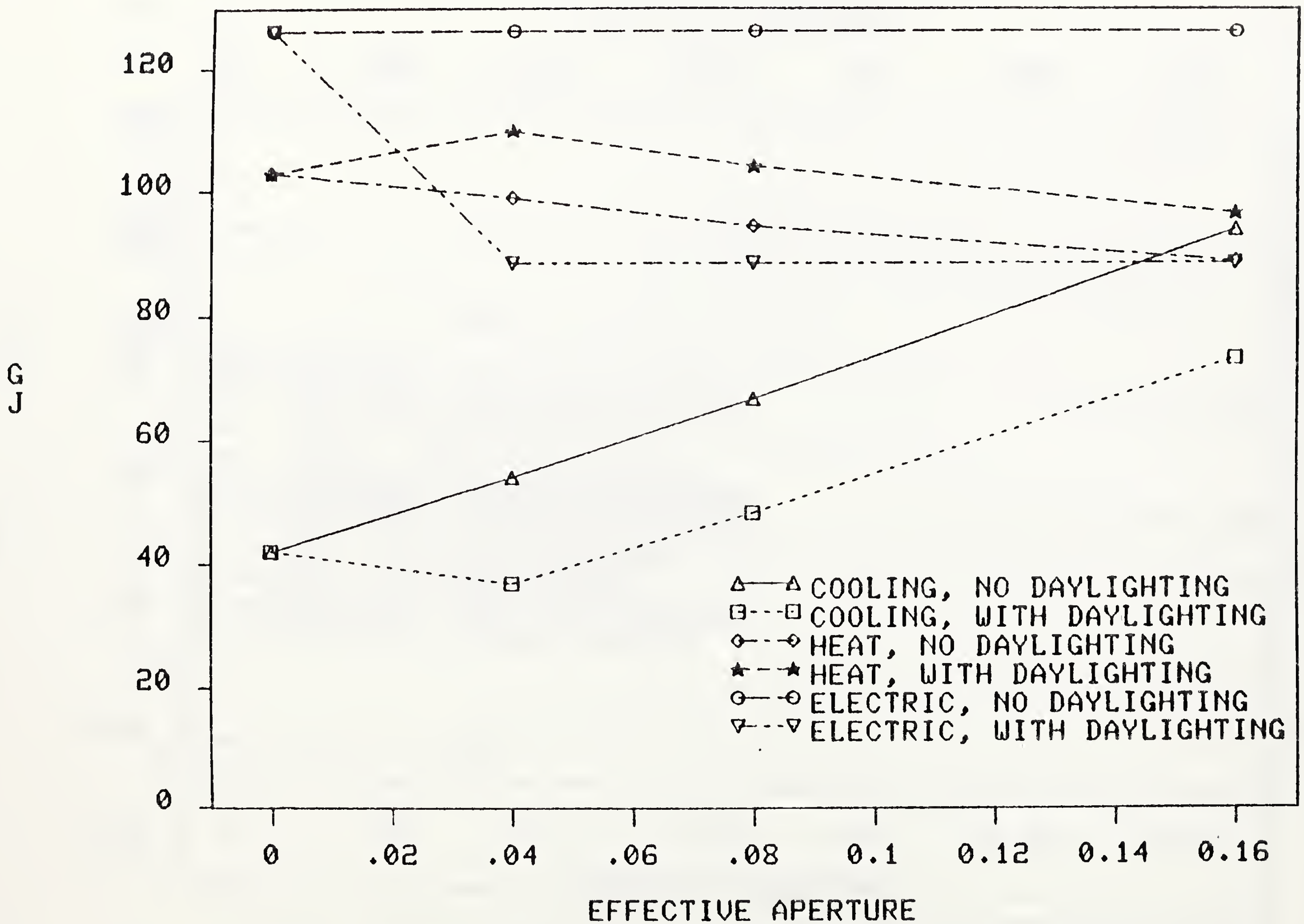


Figure 212. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
NORTH SAWTOOTH, METAL ATTACHED

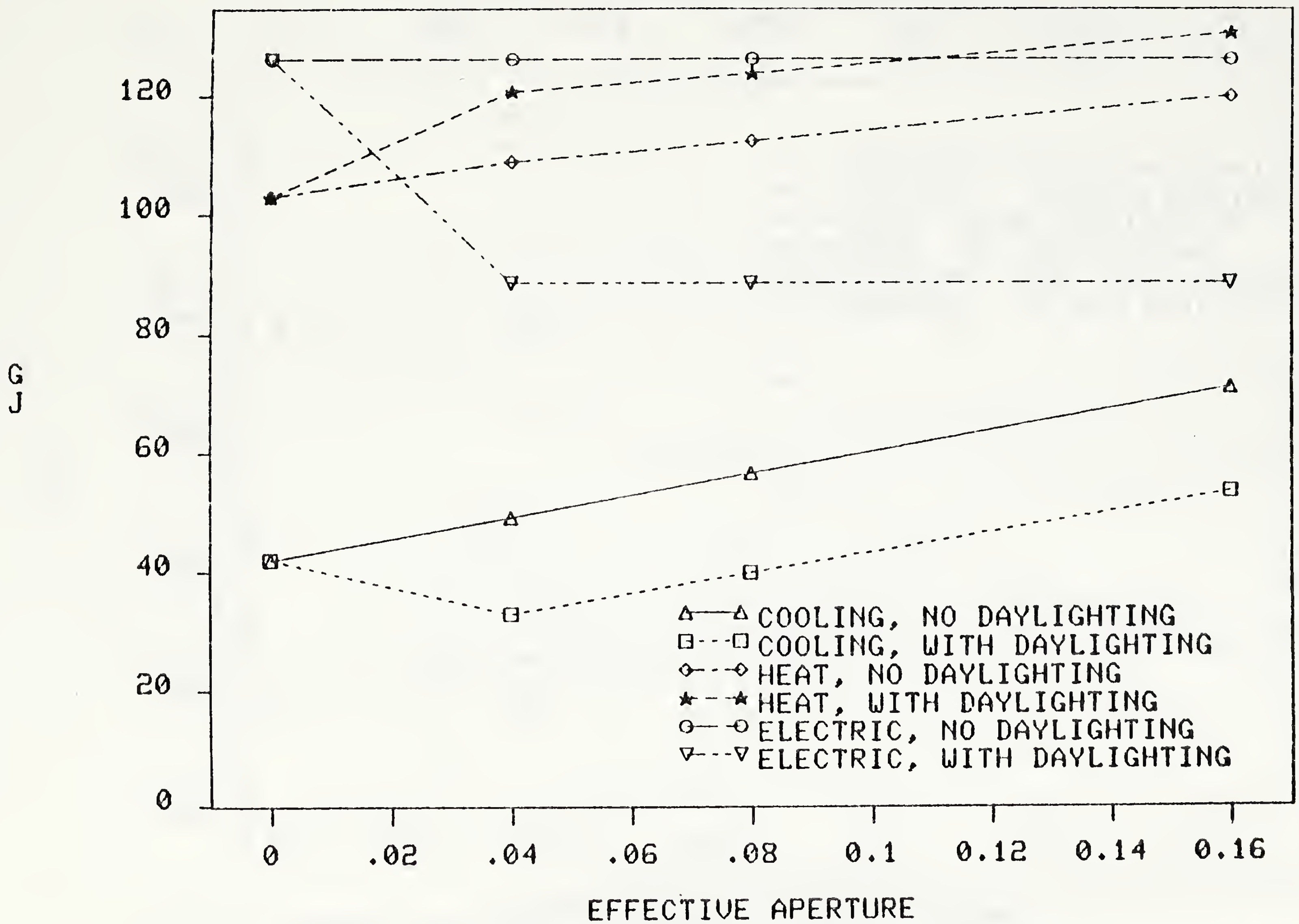


Figure 213. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
SOUTH WINDOW, METAL ATTACHED

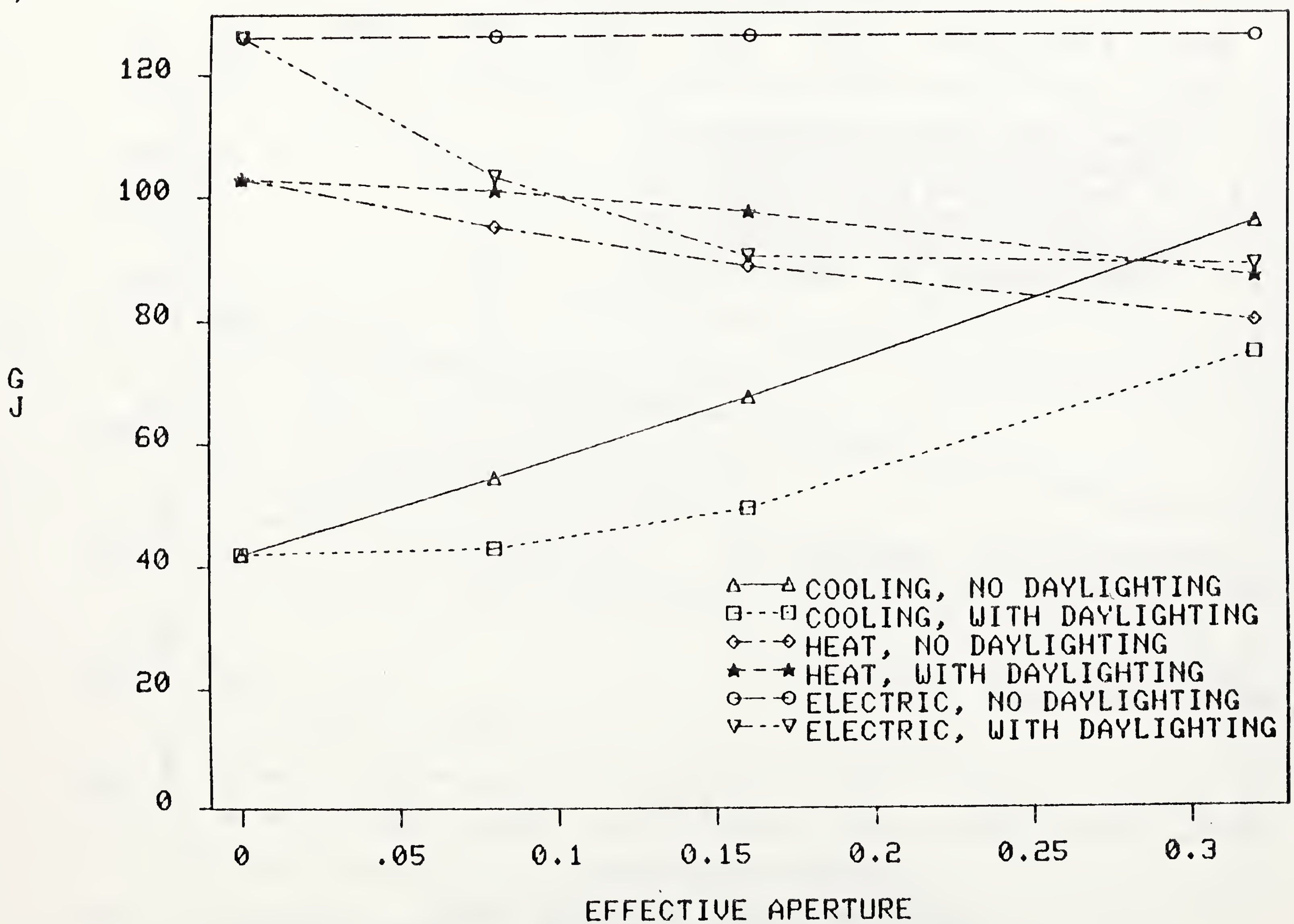


Figure 214. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Norfolk)
NORTH WINDOW, METAL ATTACHED

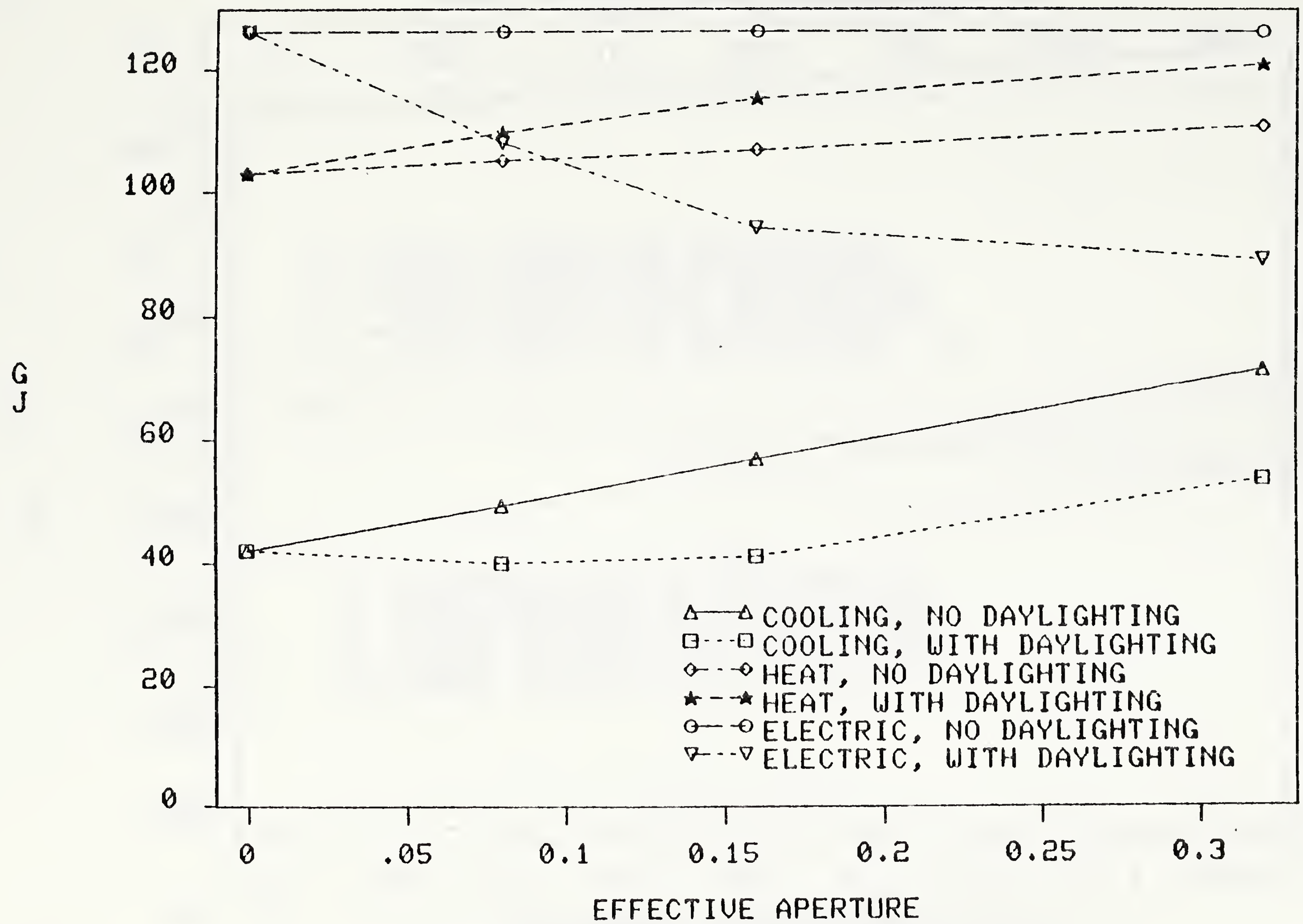


Figure 215. PEAK HEATING AND COOLING LOADS (Norfolk) SKYLIGHTS, BRICK FREESTANDING

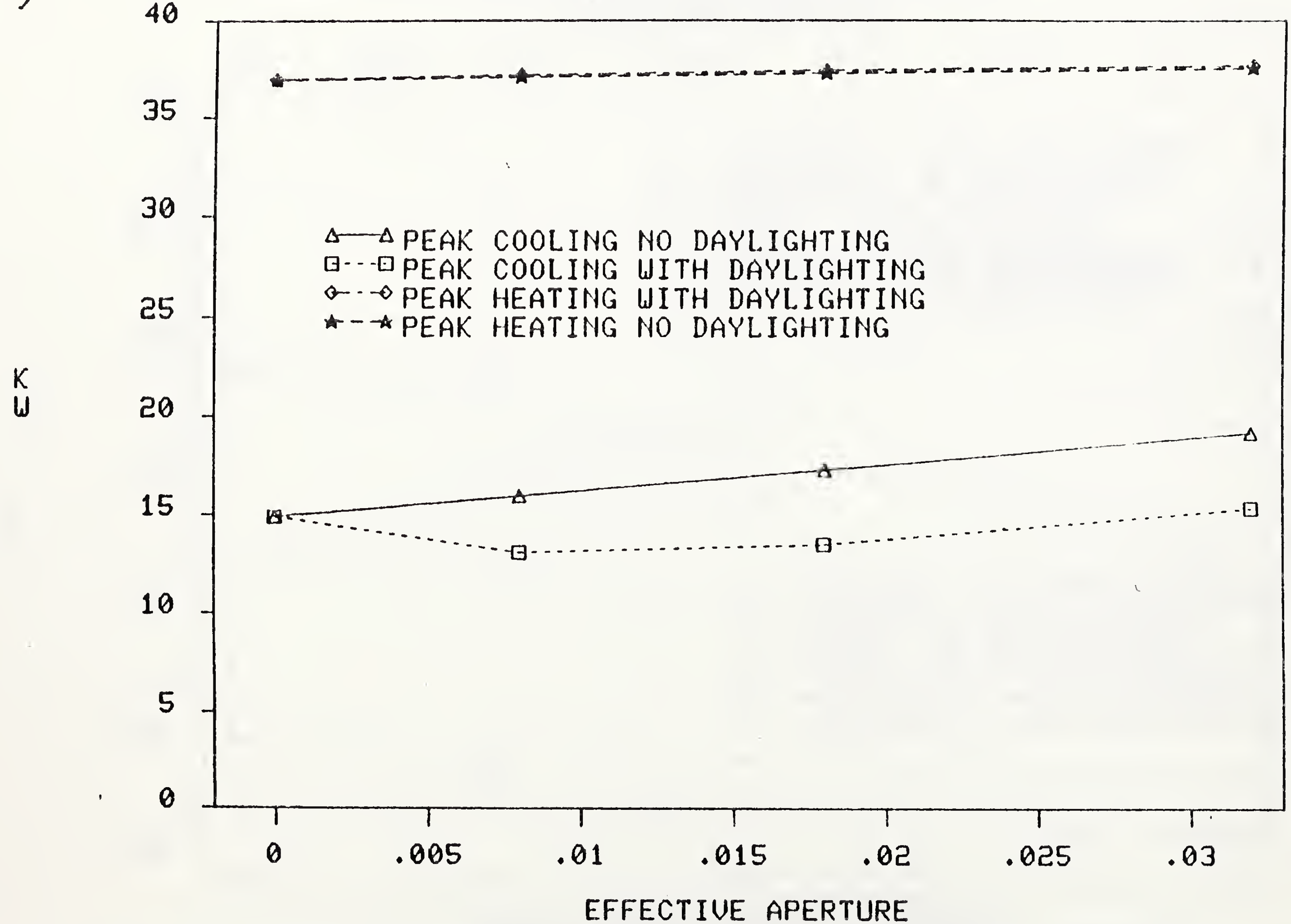


Figure 216. PEAK HEATING AND COOLING LOADS (Norfolk)
SOUTH SAWTOOTH, BRICK FREESTANDING

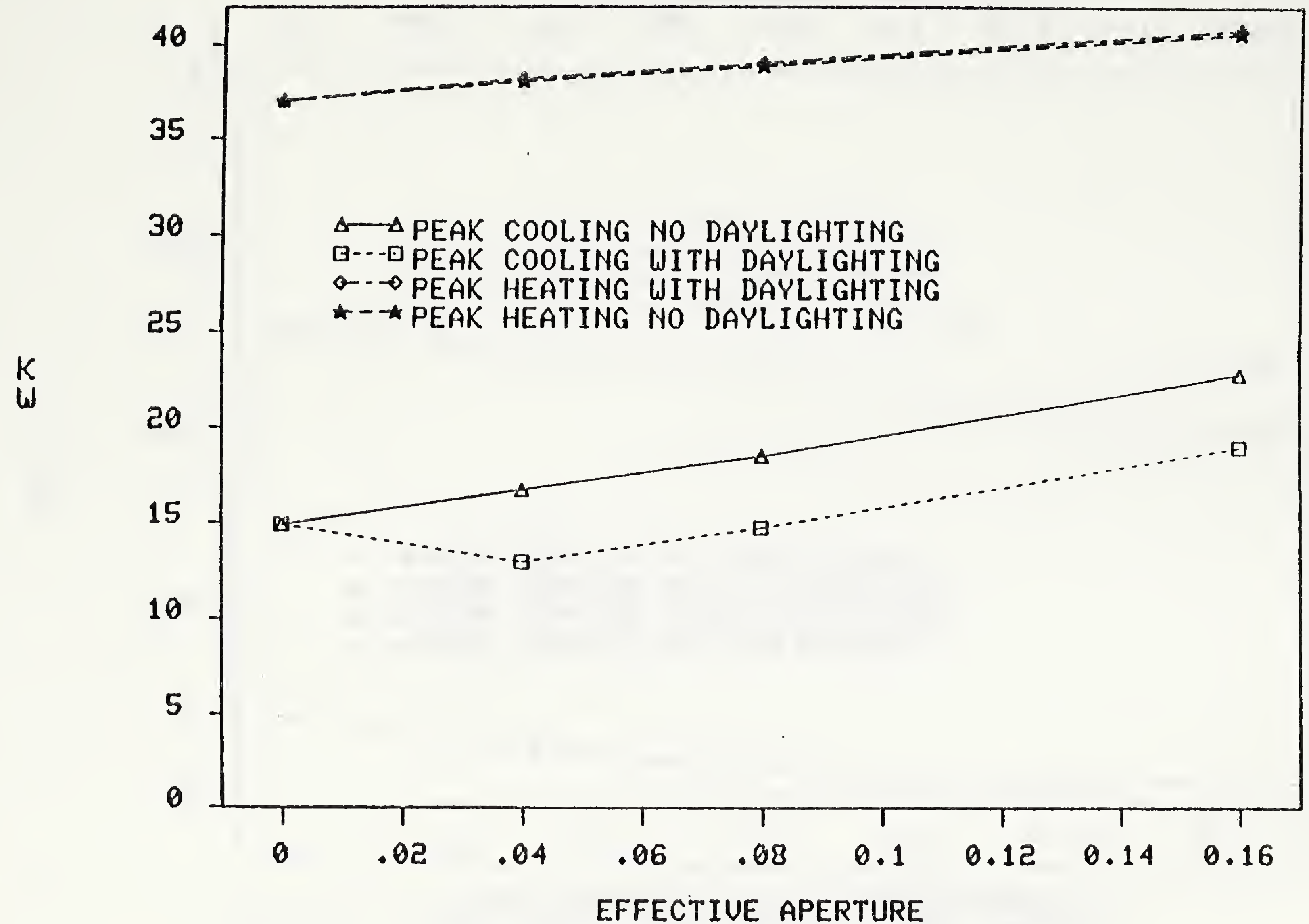


Figure 217. PEAK HEATING AND COOLING LOADS (Norfolk)
NORTH SAWTOOTH, BRICK FREESTANDING

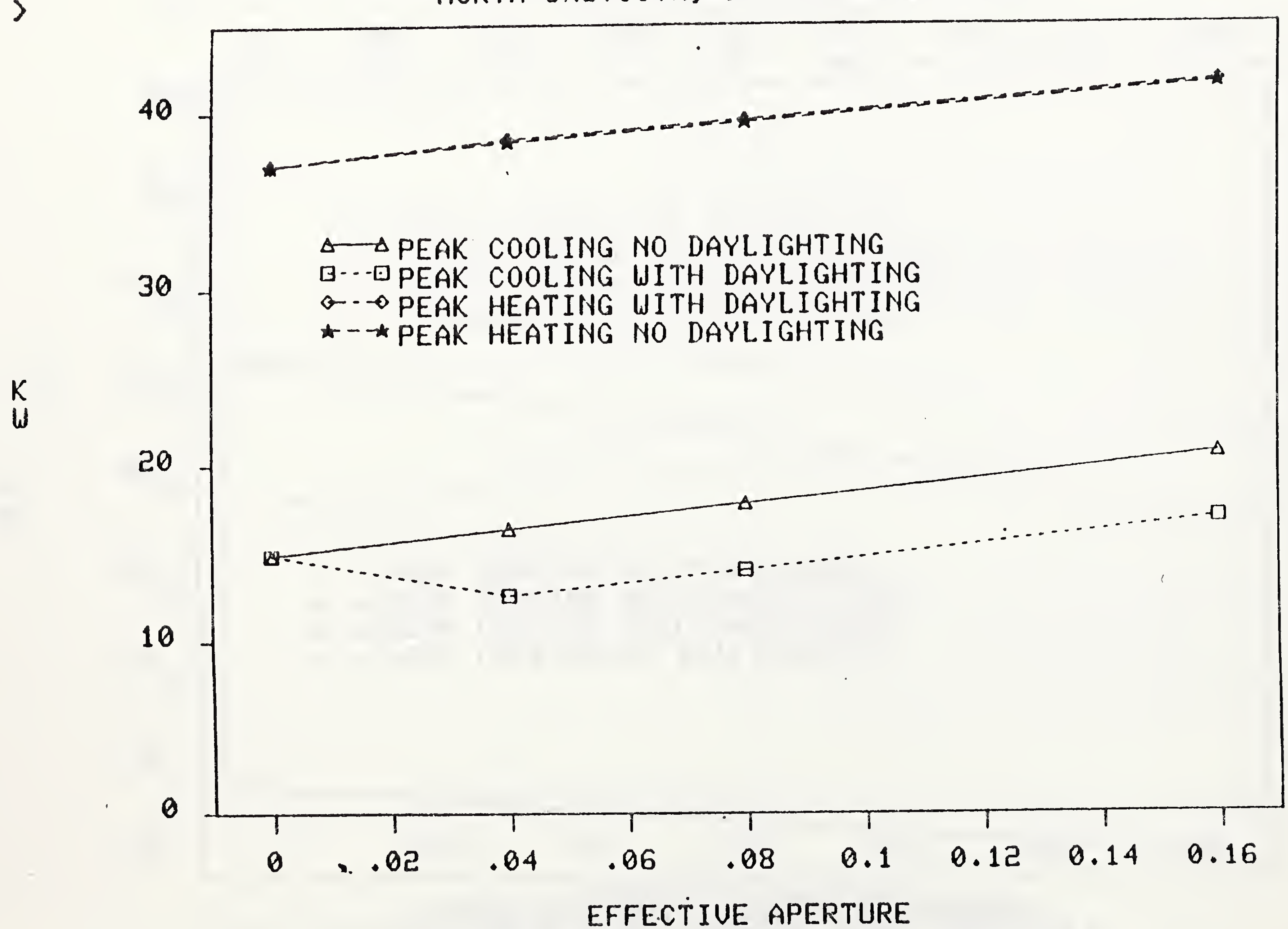


Figure 218. PEAK HEATING AND COOLING LOADS (Norfolk)
SOUTH WINDOW, BRICK FREESTANDING

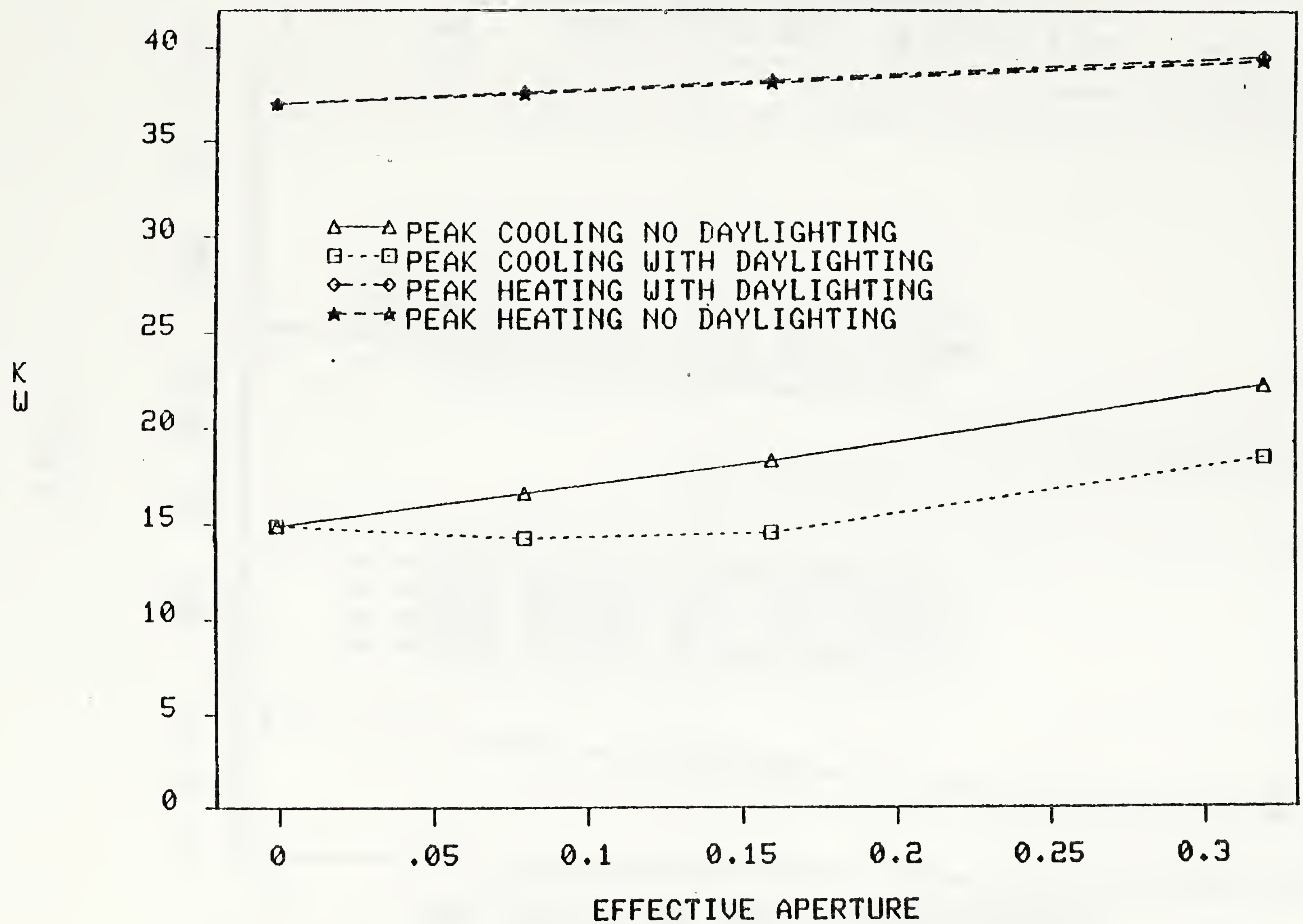


Figure 219. PEAK HEATING AND COOLING LOADS (Norfolk)
NORTH WINDOW, BRICK FREESTANDING

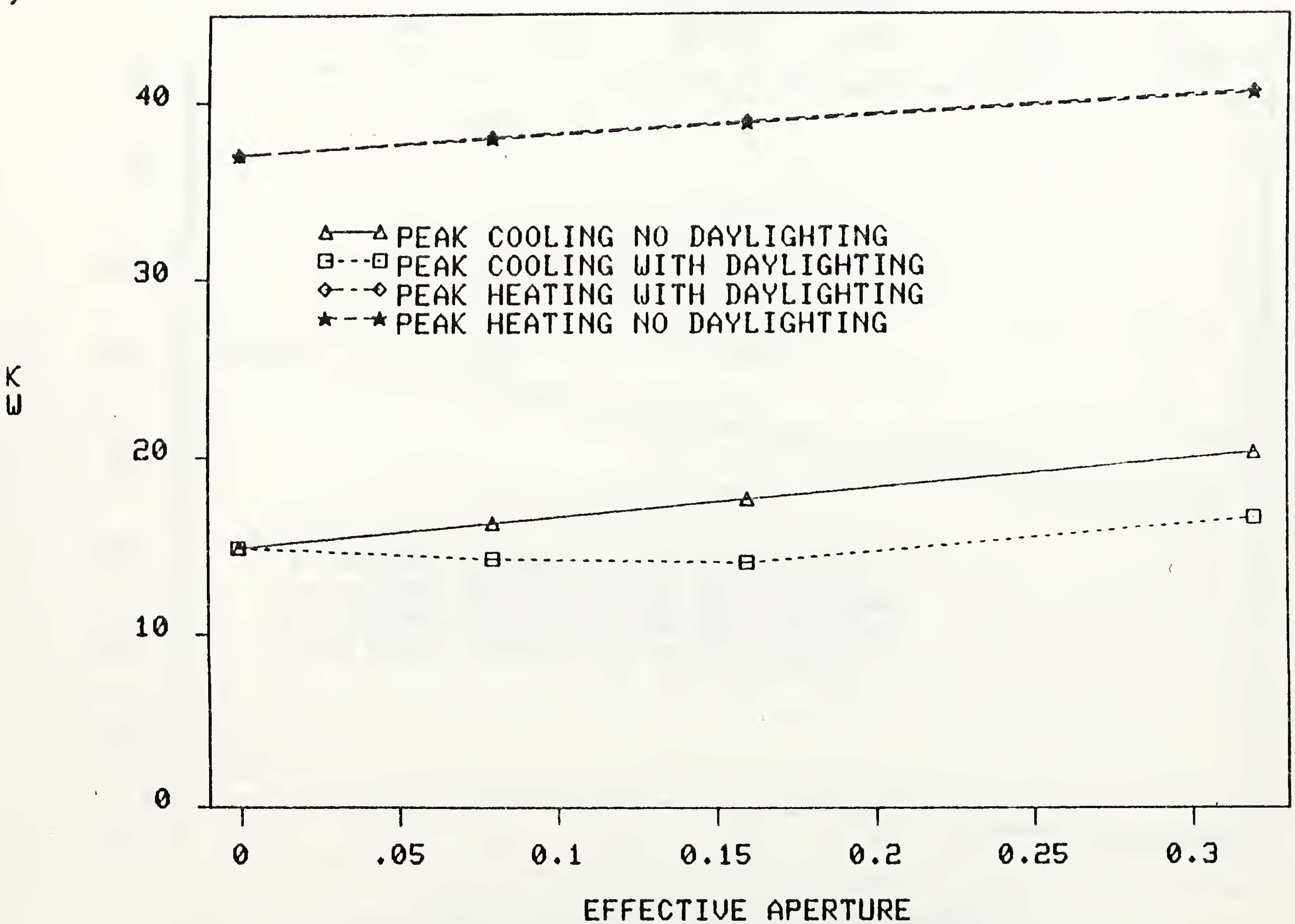


Figure 220. PEAK HEATING AND COOLING LOADS (Norfolk)
SKYLIGHTS, BRICK ATTACHED

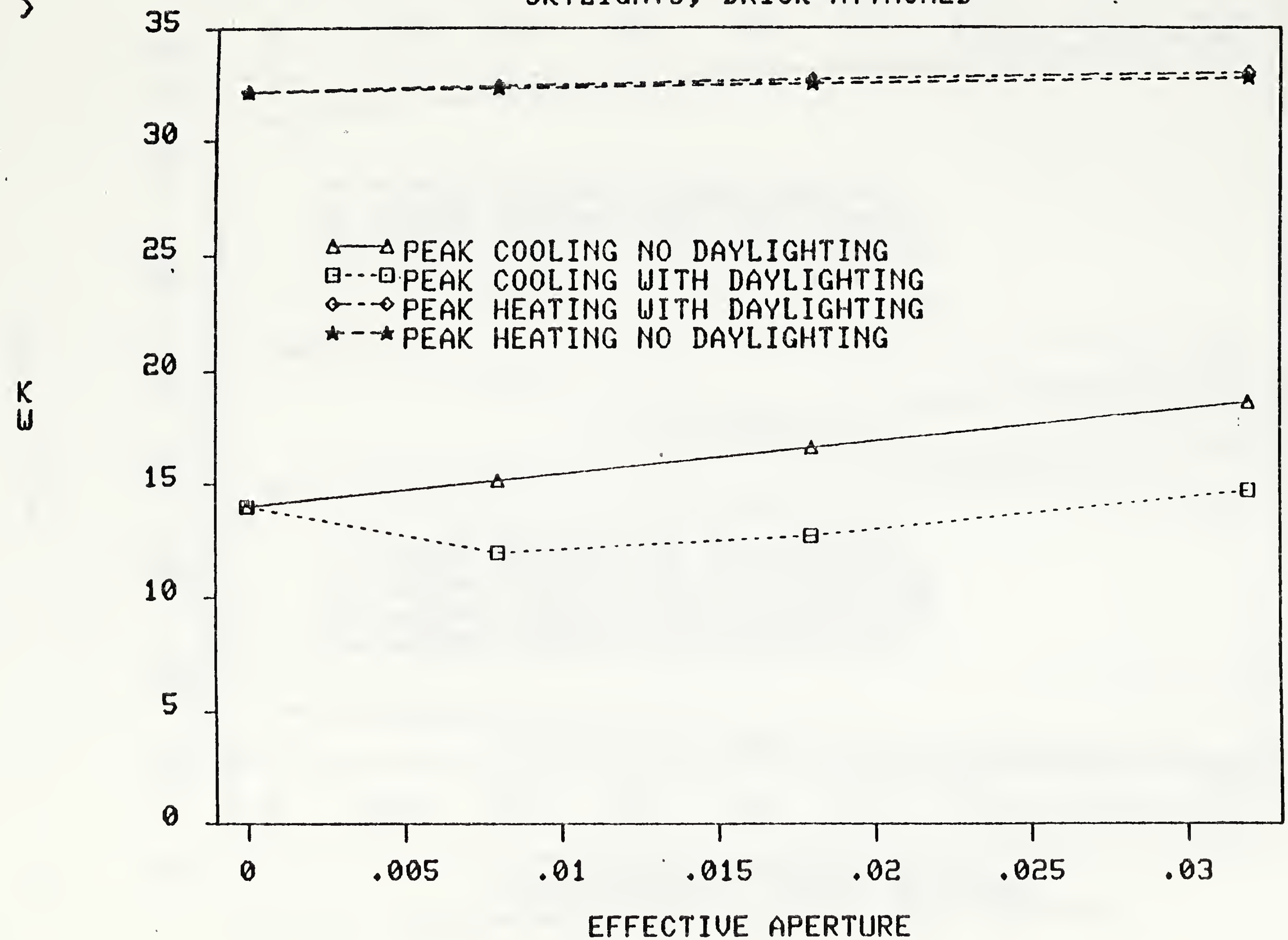


Figure 221. PEAK HEATING AND COOLING LOADS (Norfolk)
SOUTH SAWTOOTH, BRICK ATTACHED

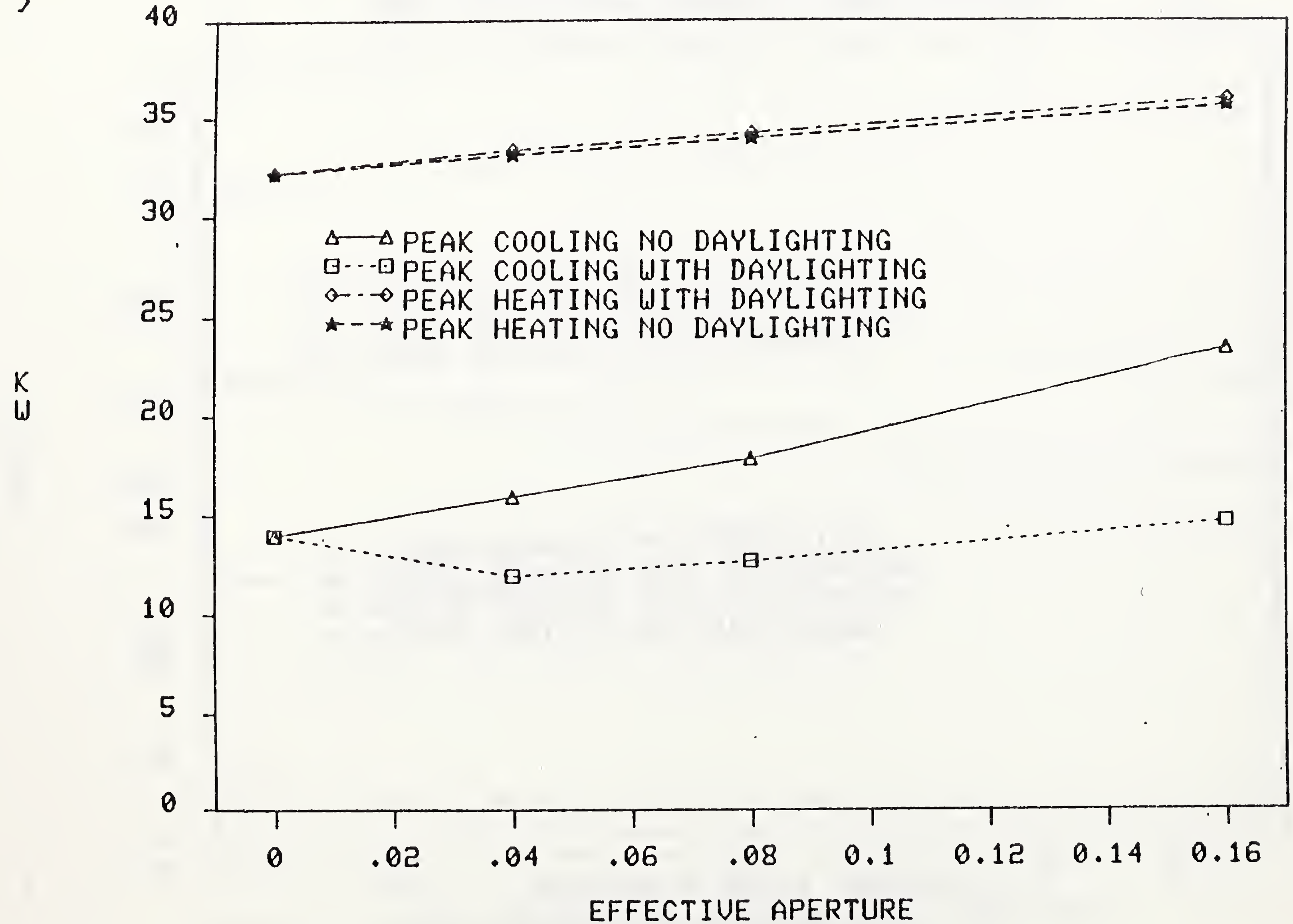


Figure 222. PEAK HEATING AND COOLING LOADS (Norfolk)
NORTH SAWTOOTH, BRICK ATTACHED

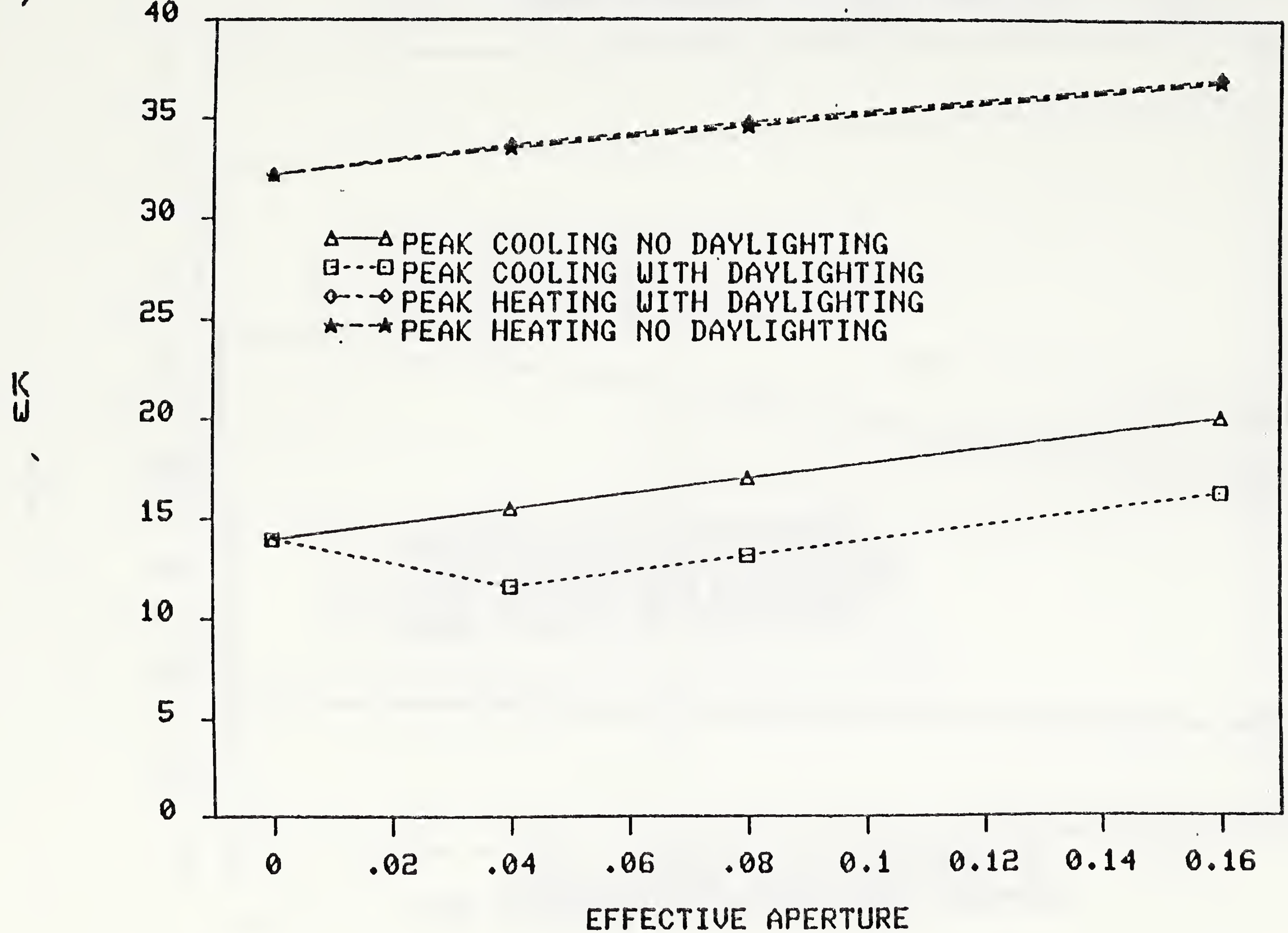


Figure 223. PEAK HEATING AND COOLING LOADS (Norfolk)
SOUTH WINDOW, BRICK ATTACHED

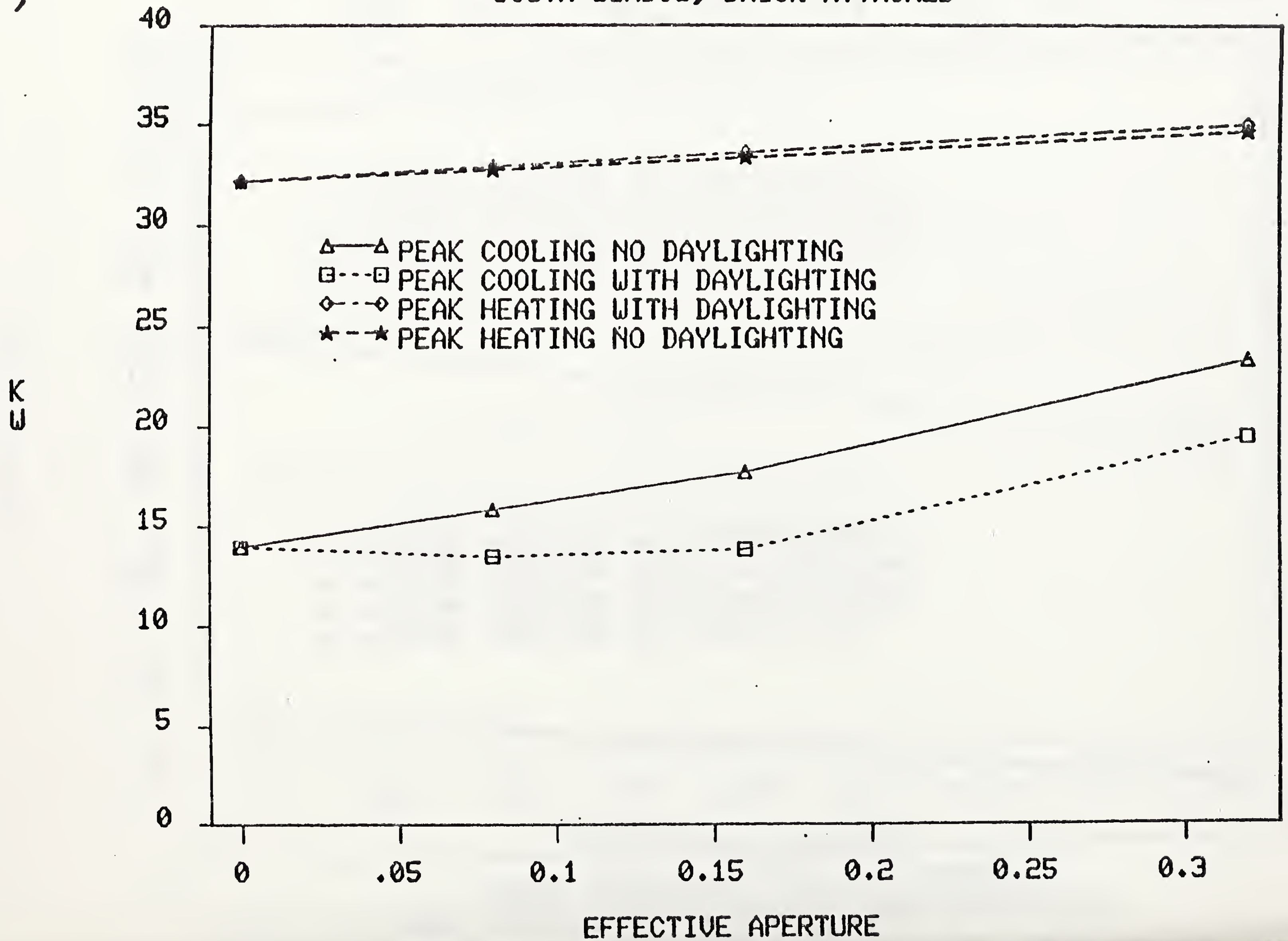


Figure 224. PEAK HEATING AND COOLING LOADS (Norfolk)
NORTH WINDOW, BRICK ATTACHED

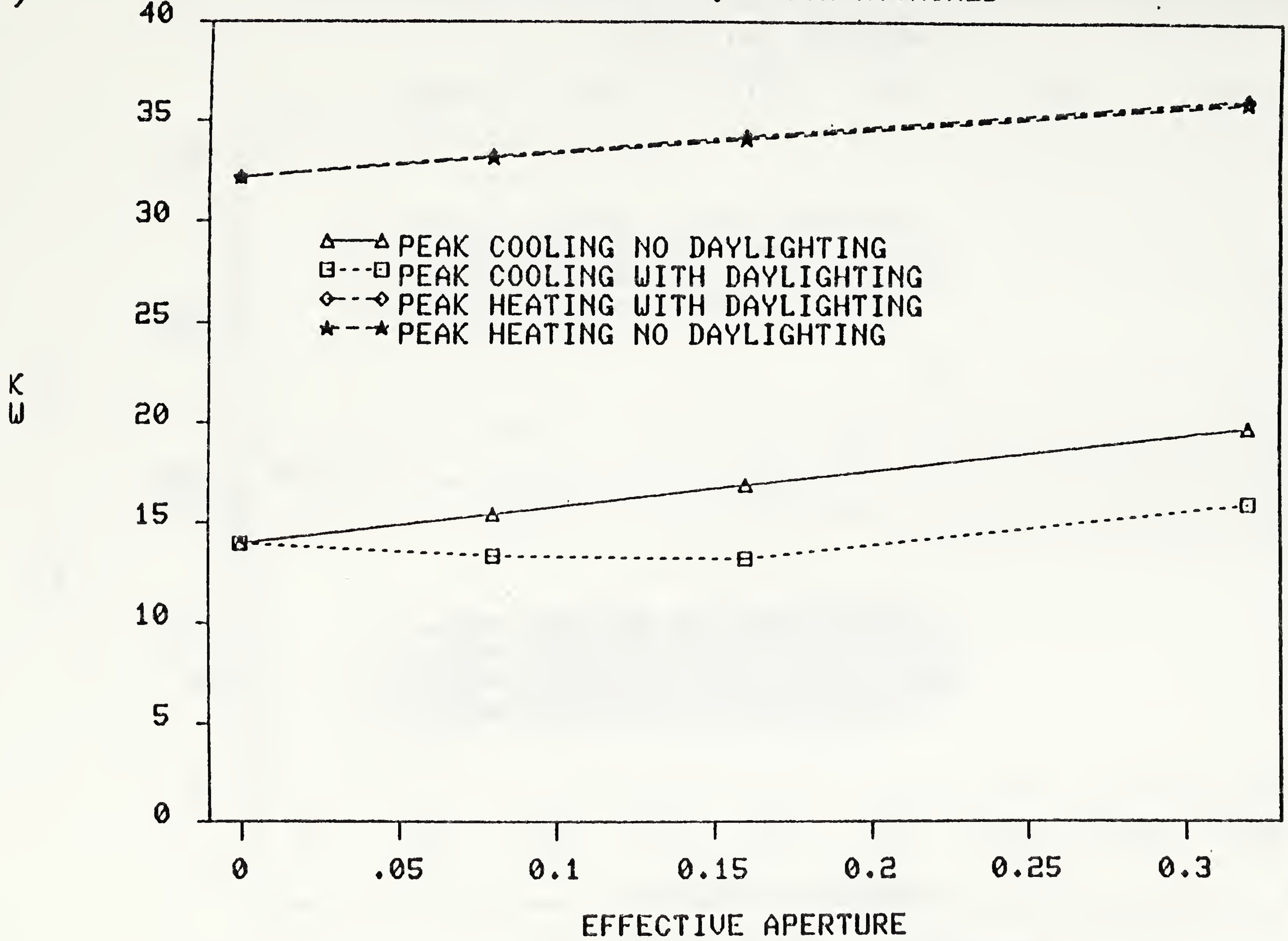


Figure 225. PEAK HEATING AND COOLING LOADS (Norfolk) SKYLIGHTS, METAL FREESTANDING

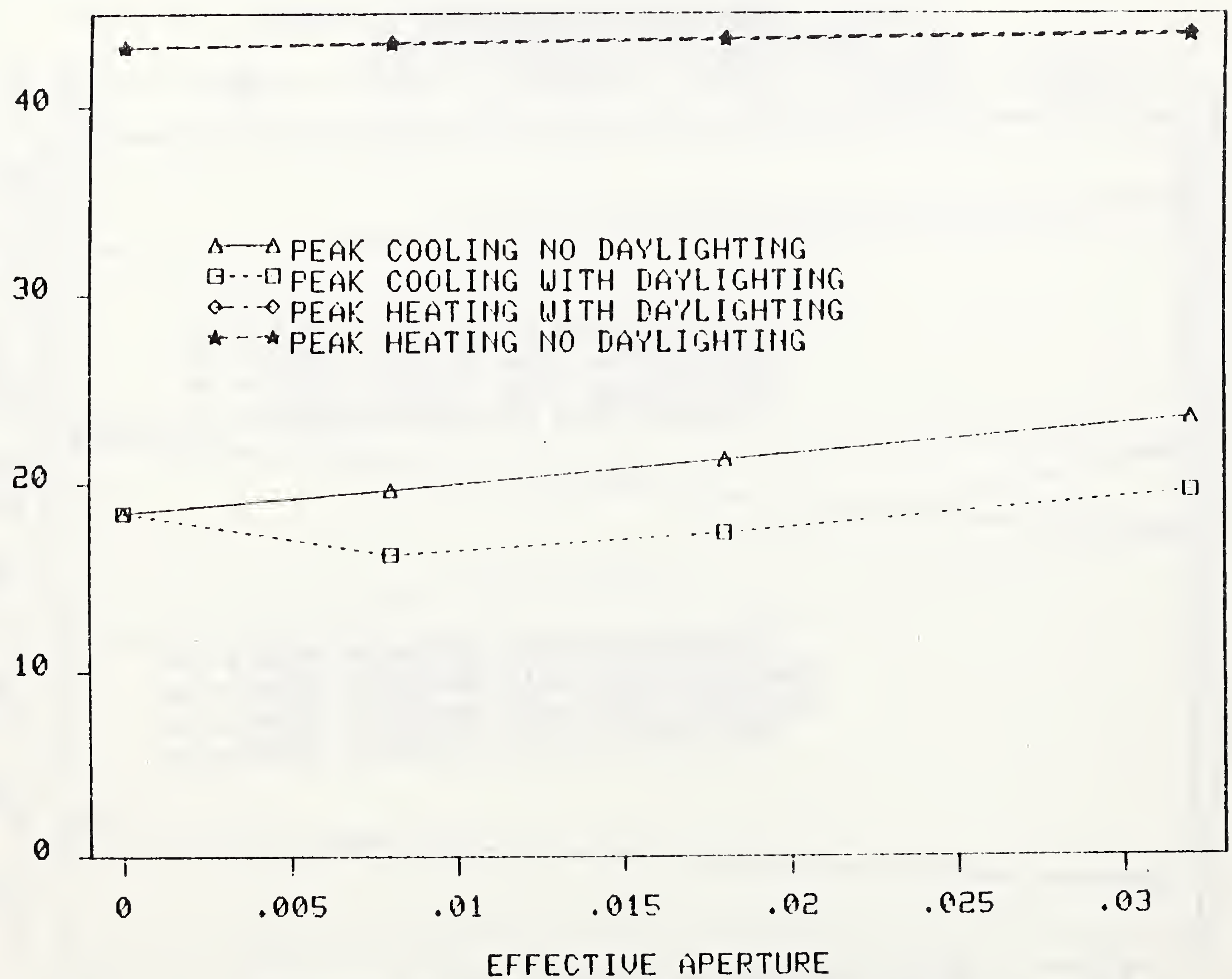


Figure 226. PEAK HEATING AND COOLING LOADS (Norfolk)
SOUTH SAWTOOTH, METAL FREESTANDING

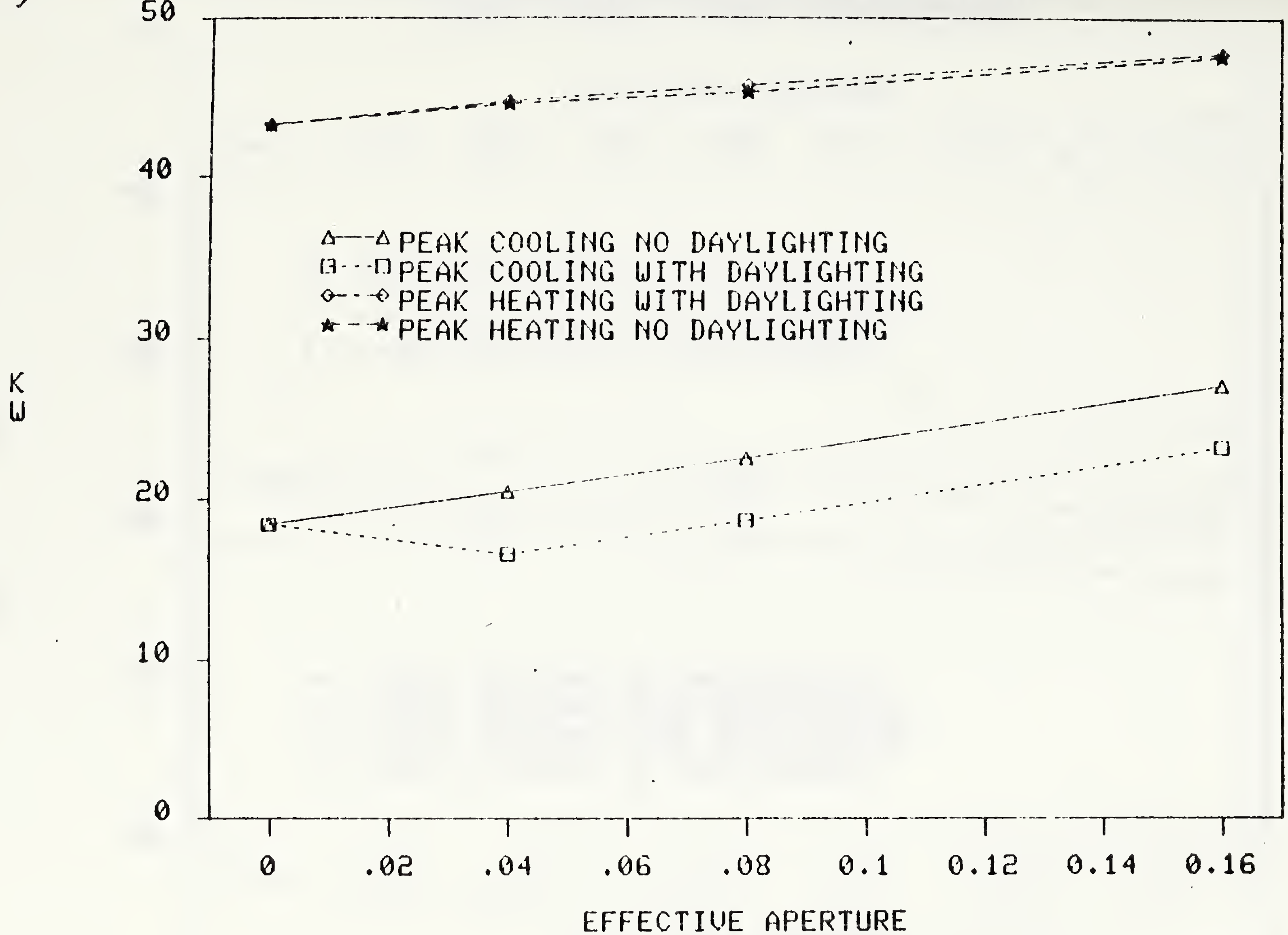


Figure 227. PEAK HEATING AND COOLING LOADS (Norfolk)
NORTH SAWTOOTH, METAL FREESTANDING

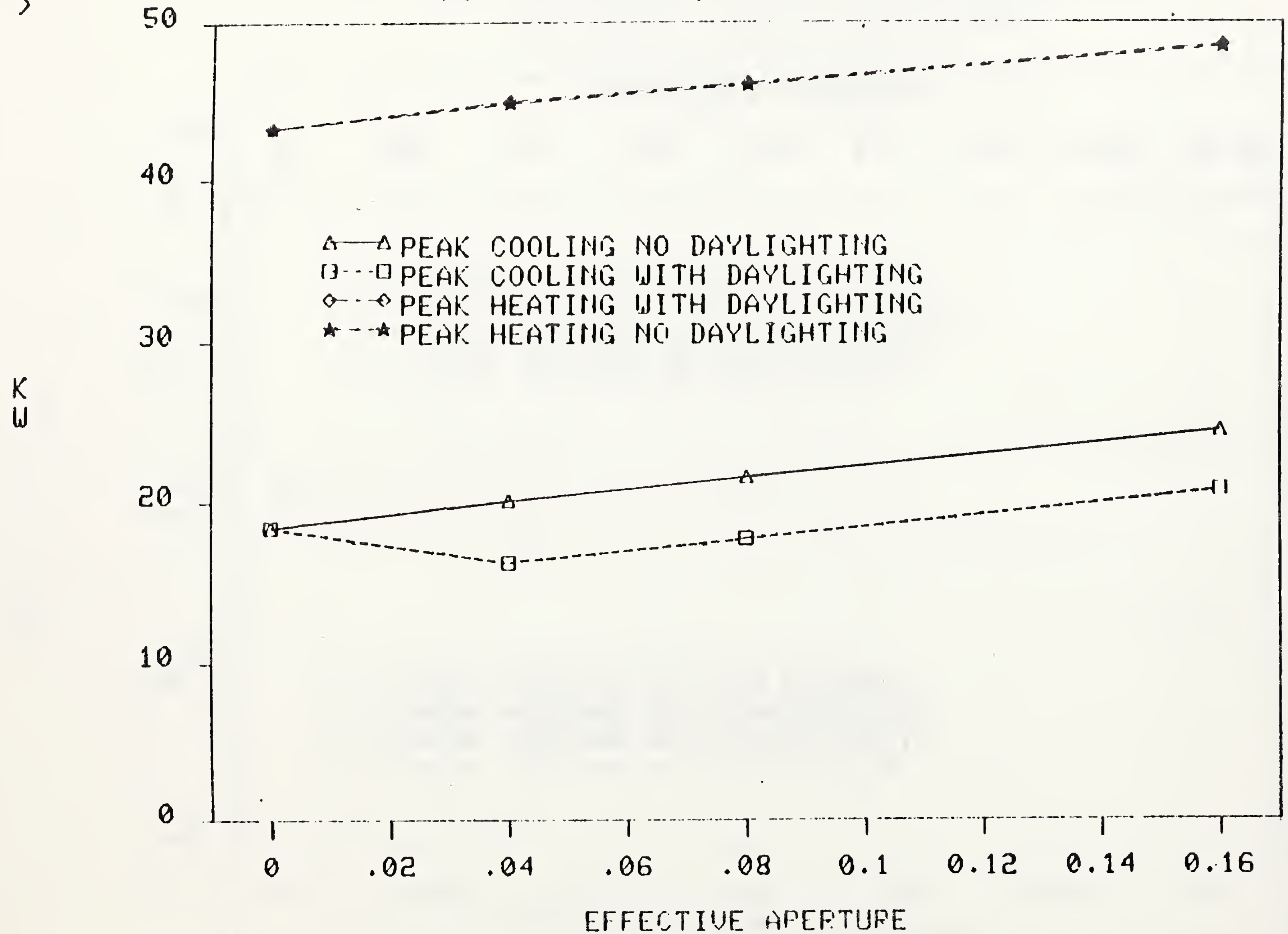


Figure 228. PEAK HEATING AND COOLING LOADS (Norfolk)
SOUTH WINDOW, METAL FREESTANDING

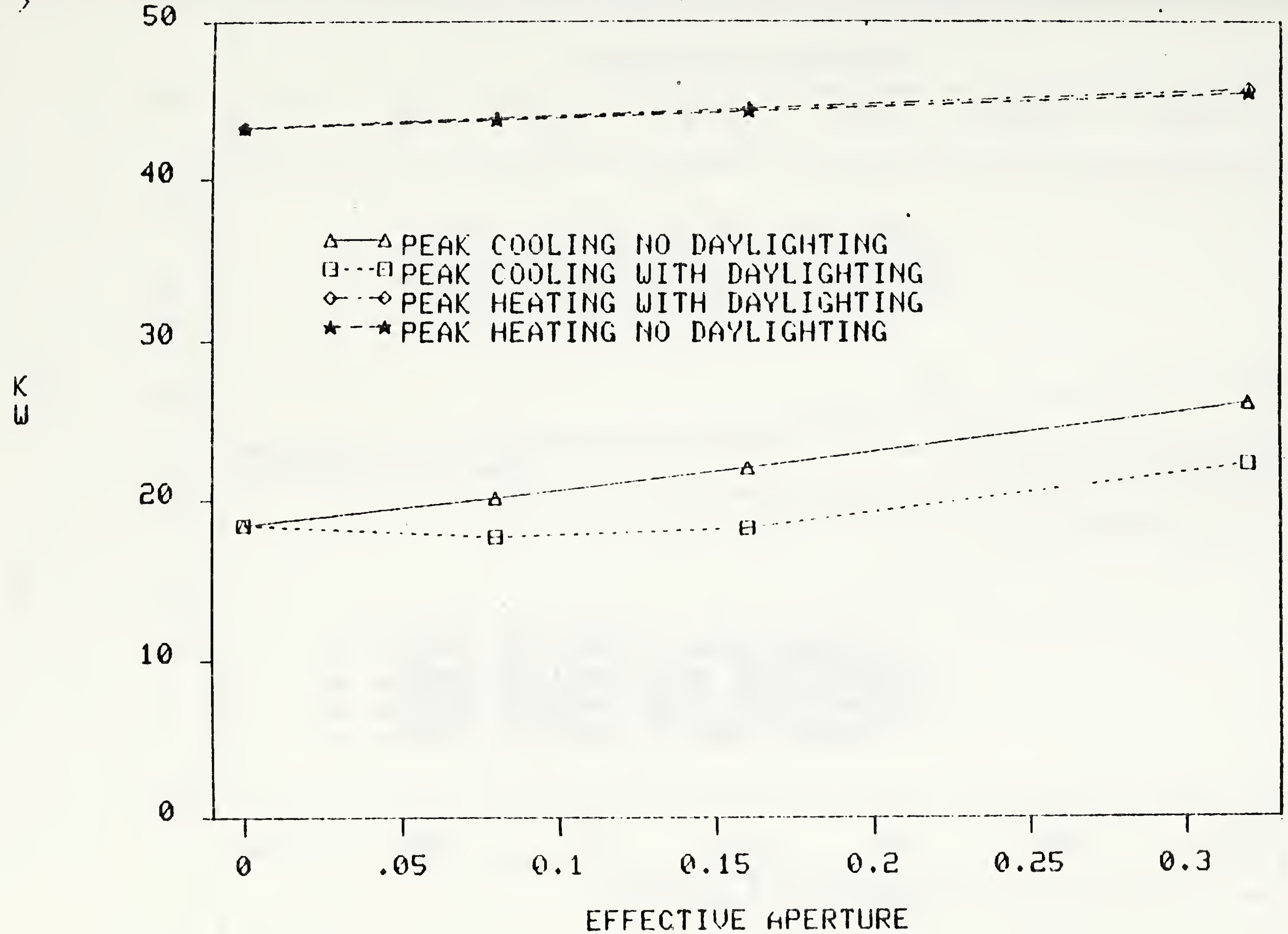


Figure 229. PEAK HEATING AND COOLING LOADS (Norfolk)
NORTH WINDOW, METAL FREESTANDING

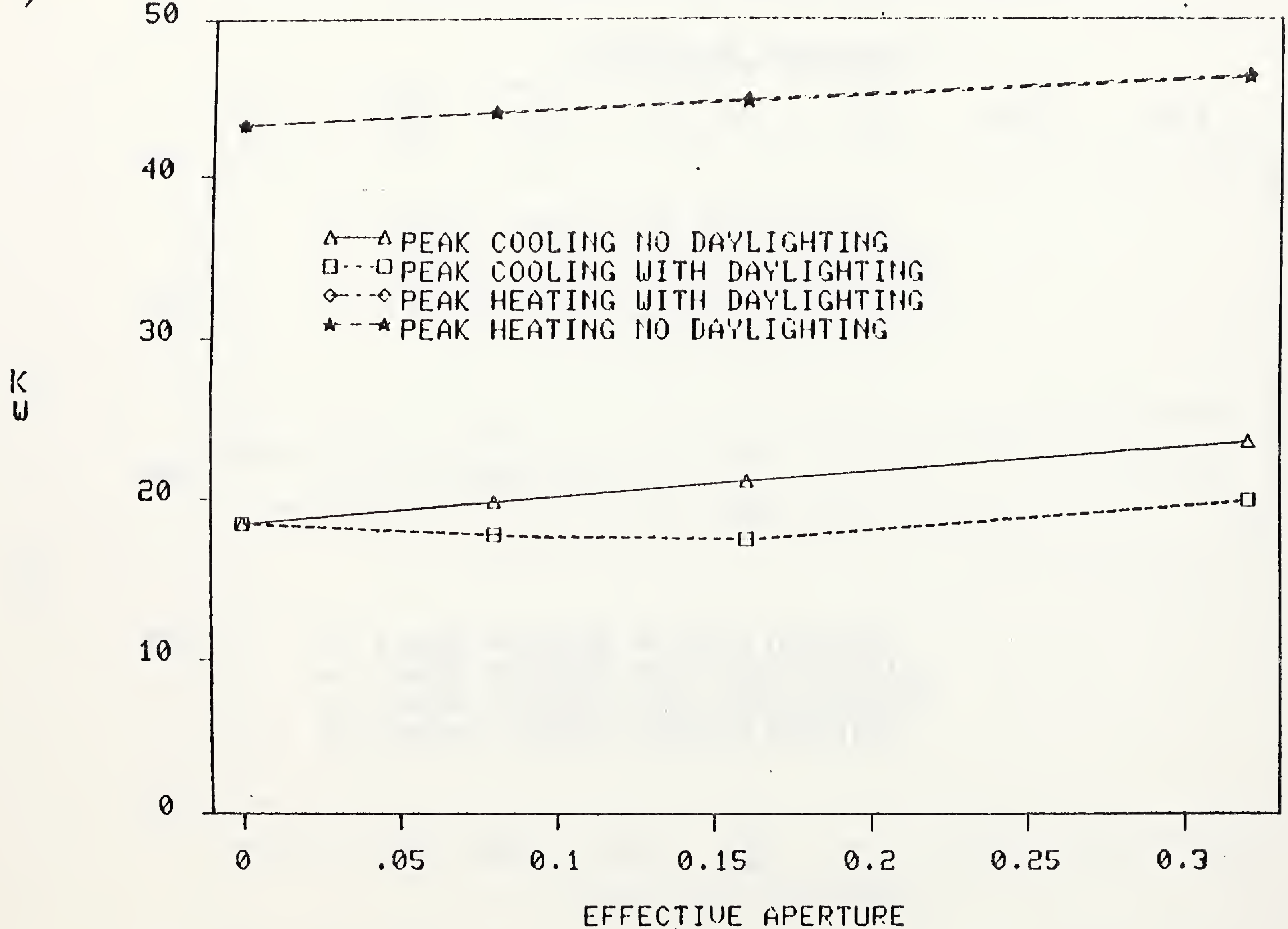


Figure 230. PEAK HEATING AND COOLING LOADS (Norfolk)
SKYLIGHTS, METAL ATTACHED

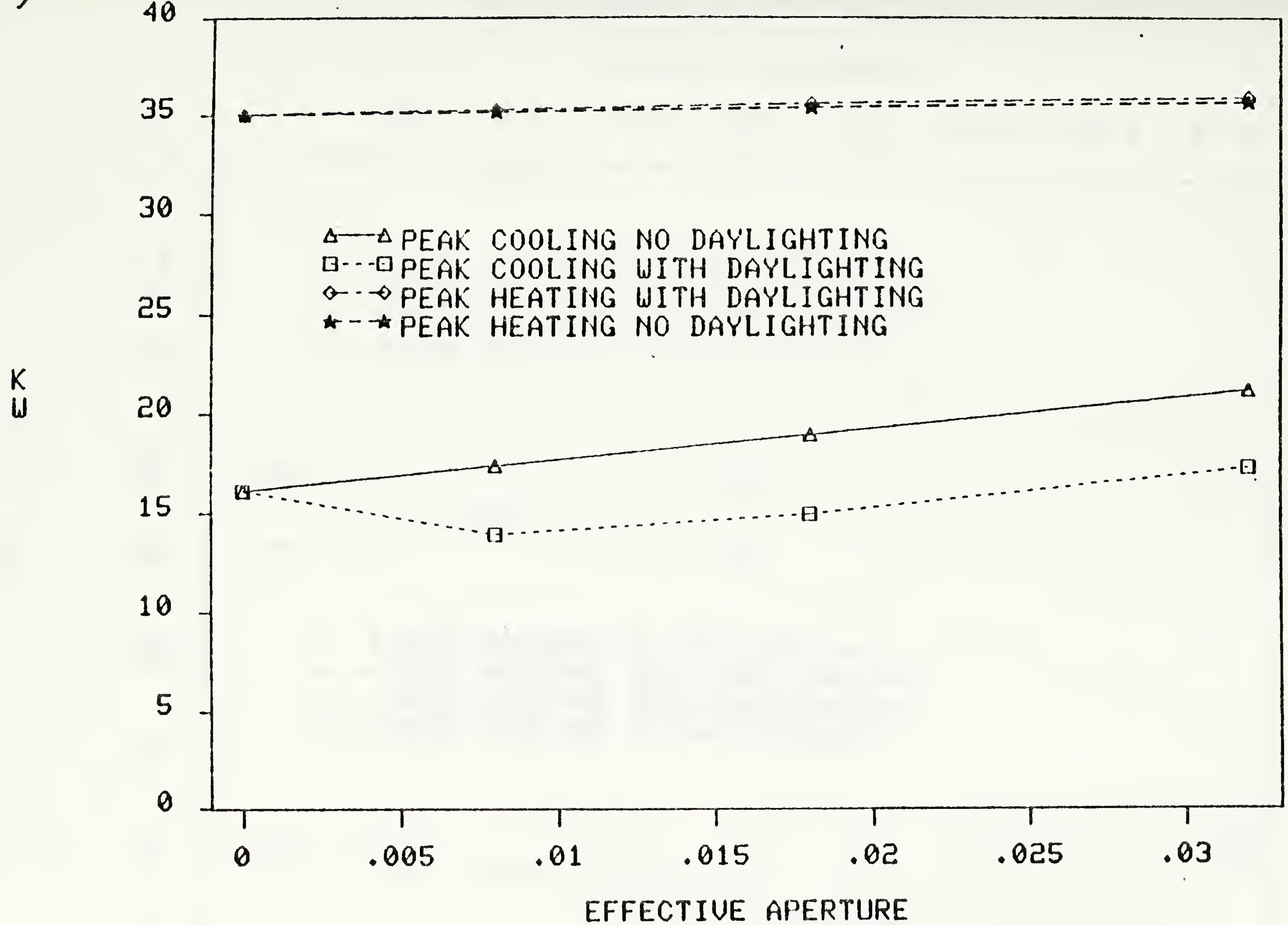


Figure 231. PEAK HEATING AND COOLING LOADS (Norfolk)
SOUTH SAWTOOTH, METAL ATTACHED

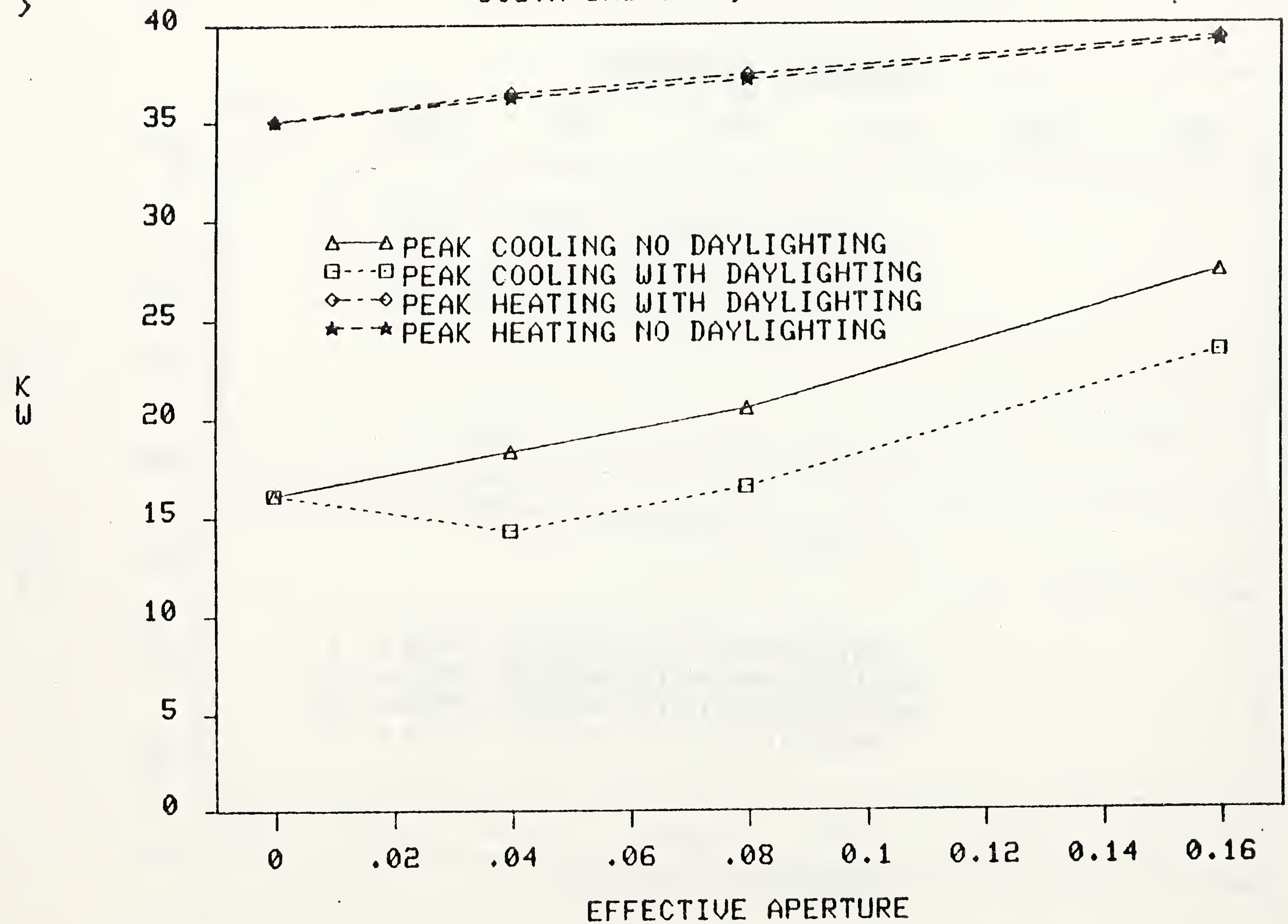


Figure 232. PEAK HEATING AND COOLING LOADS (Norfolk)
NORTH SAWTOOTH, METAL ATTACHED

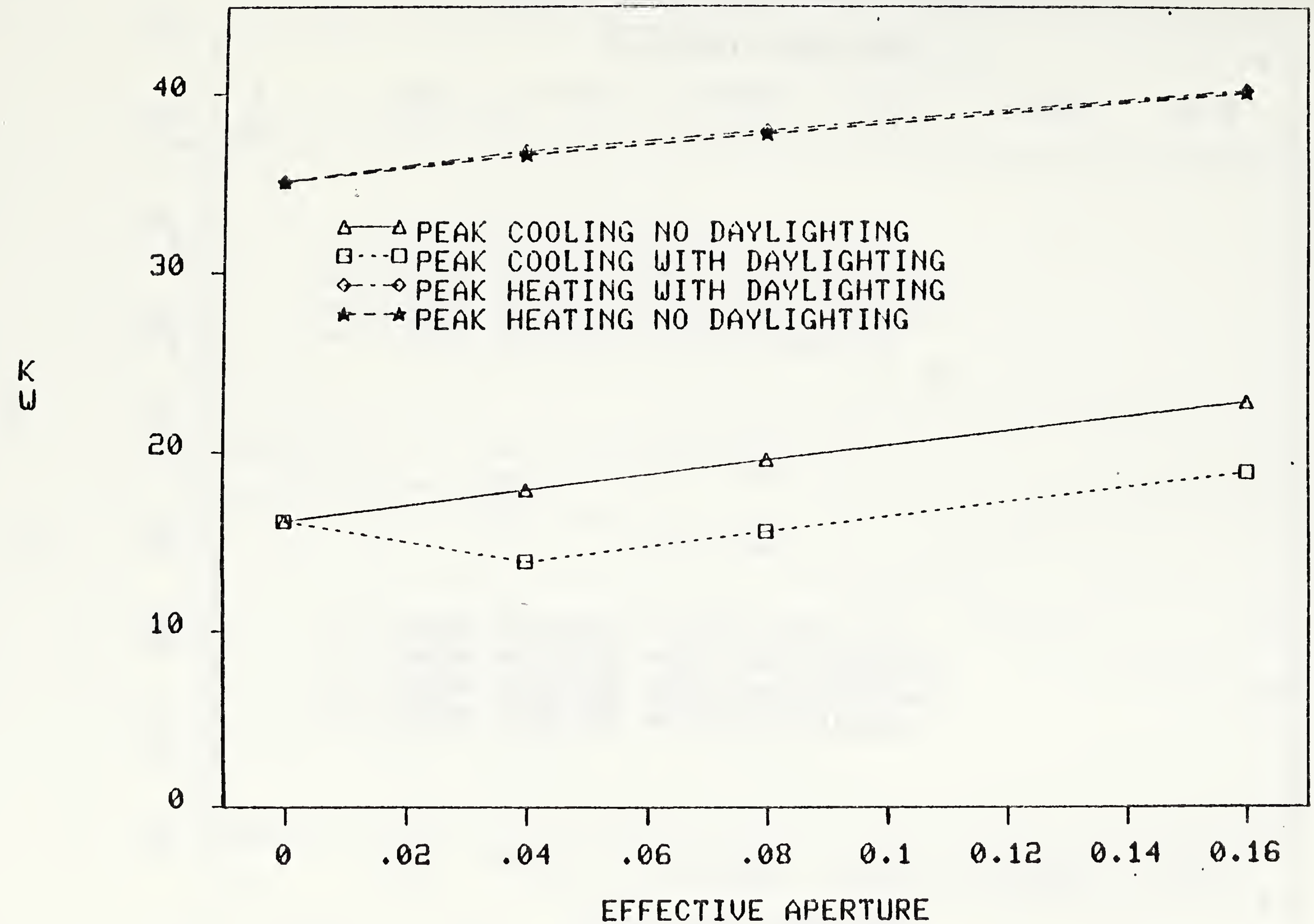


Figure 233. PEAK HEATING AND COOLING LOADS (Norfolk) SOUTH WINDOW, METAL ATTACHED

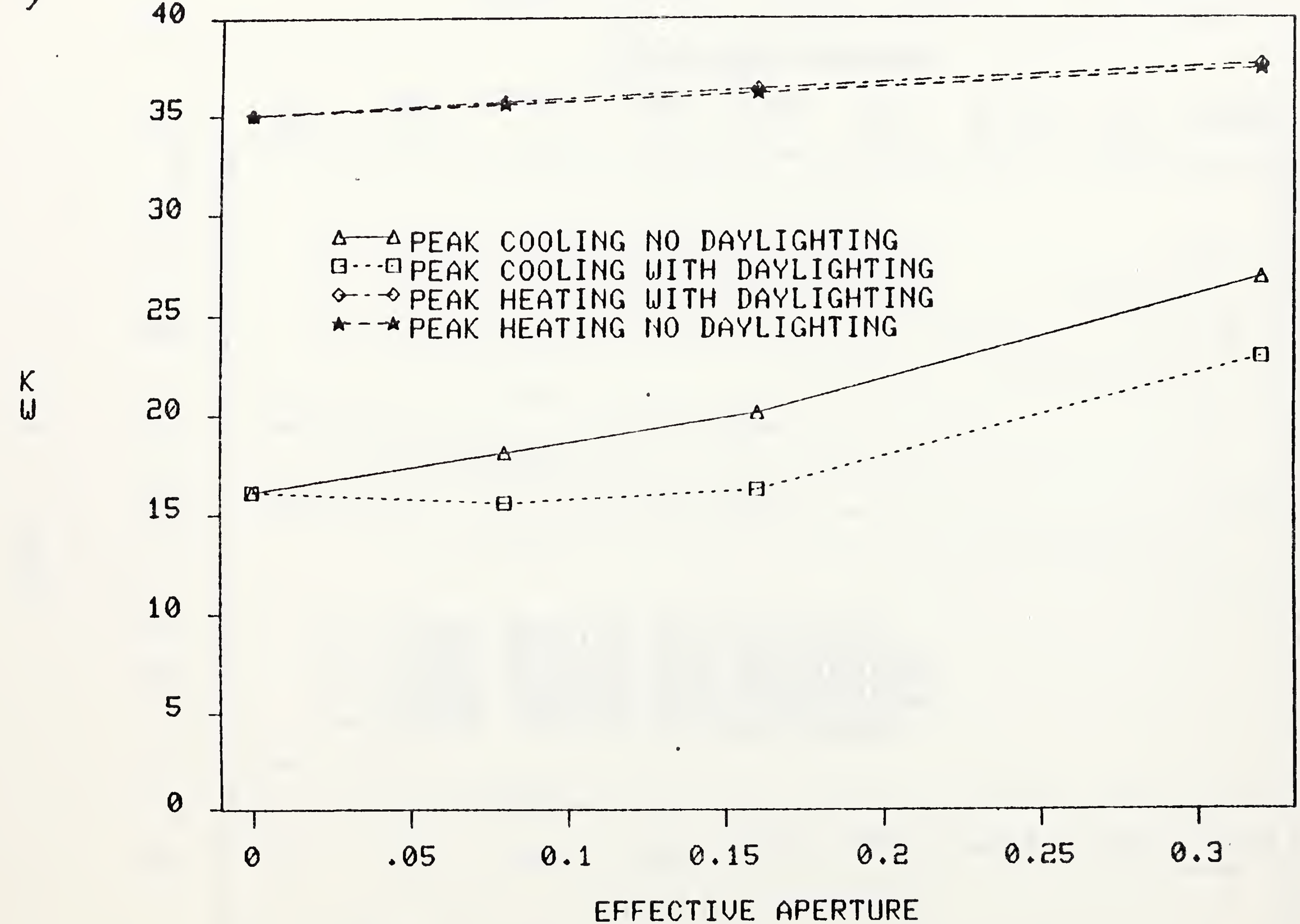


Figure 234. PEAK HEATING AND COOLING LOADS (Norfolk)
NORTH WINDOW, METAL ATTACHED

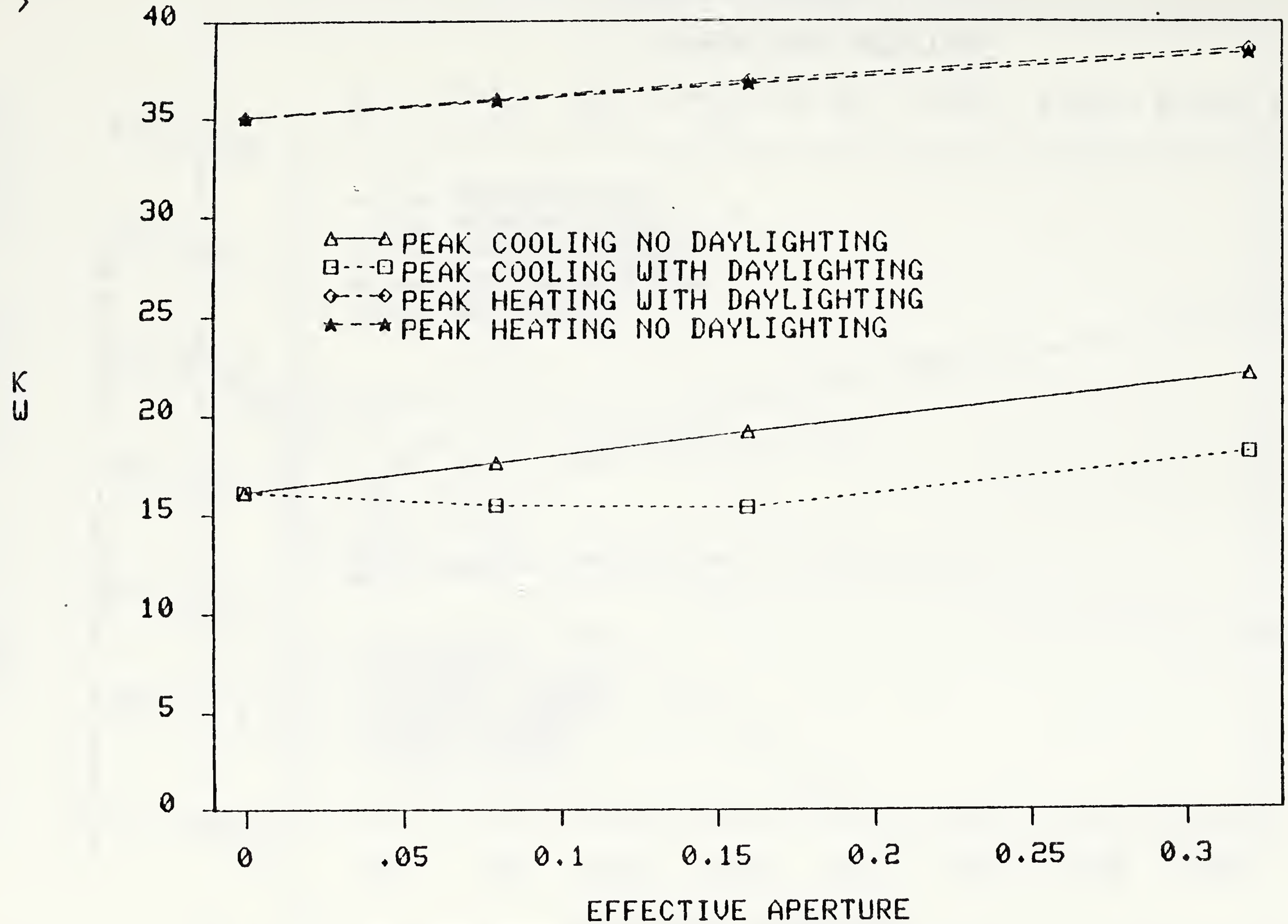


Figure 235. TOTAL ENERGY WITH DAYLIGHT (Boston)
BRICK FREESTANDING

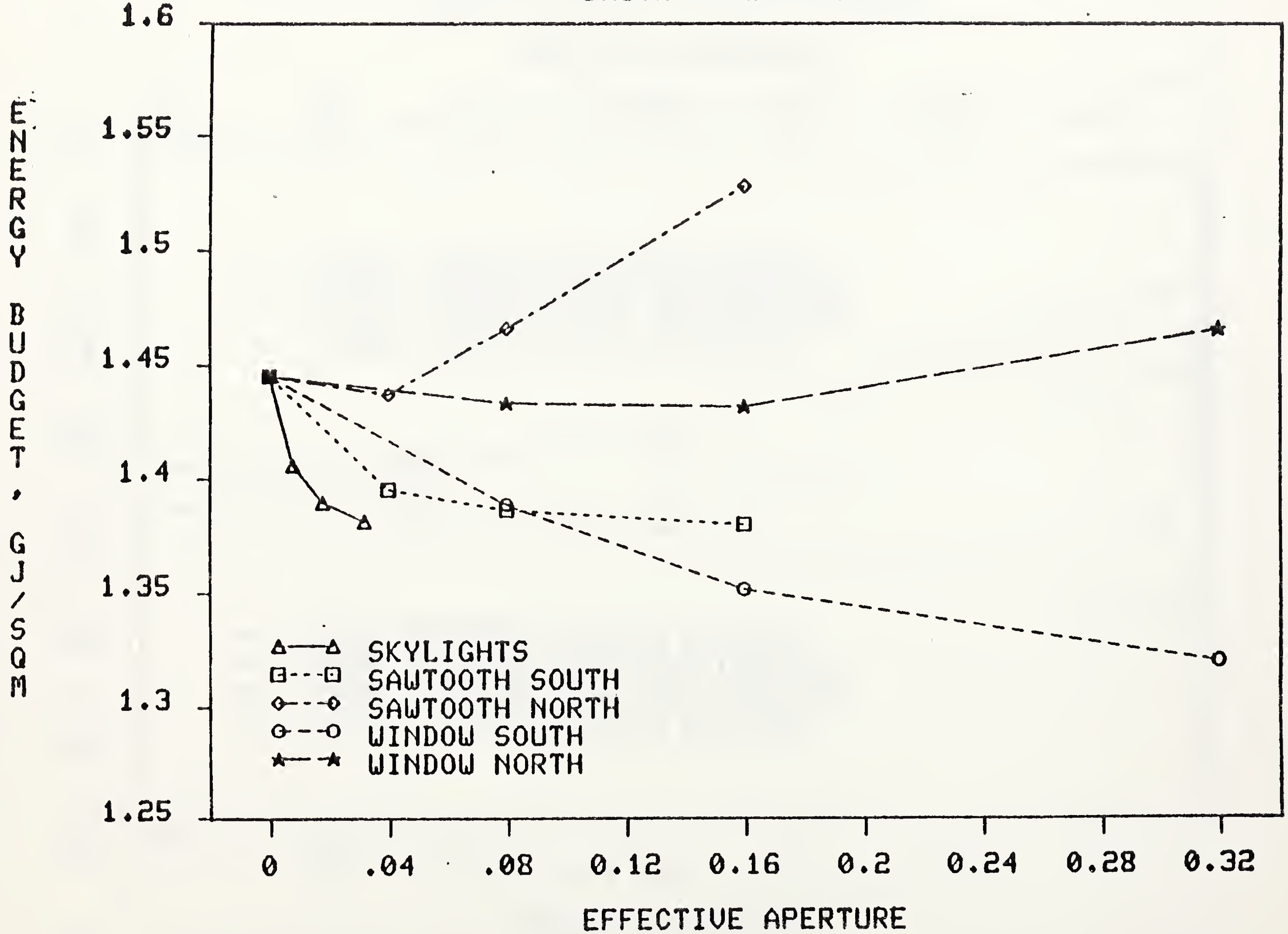
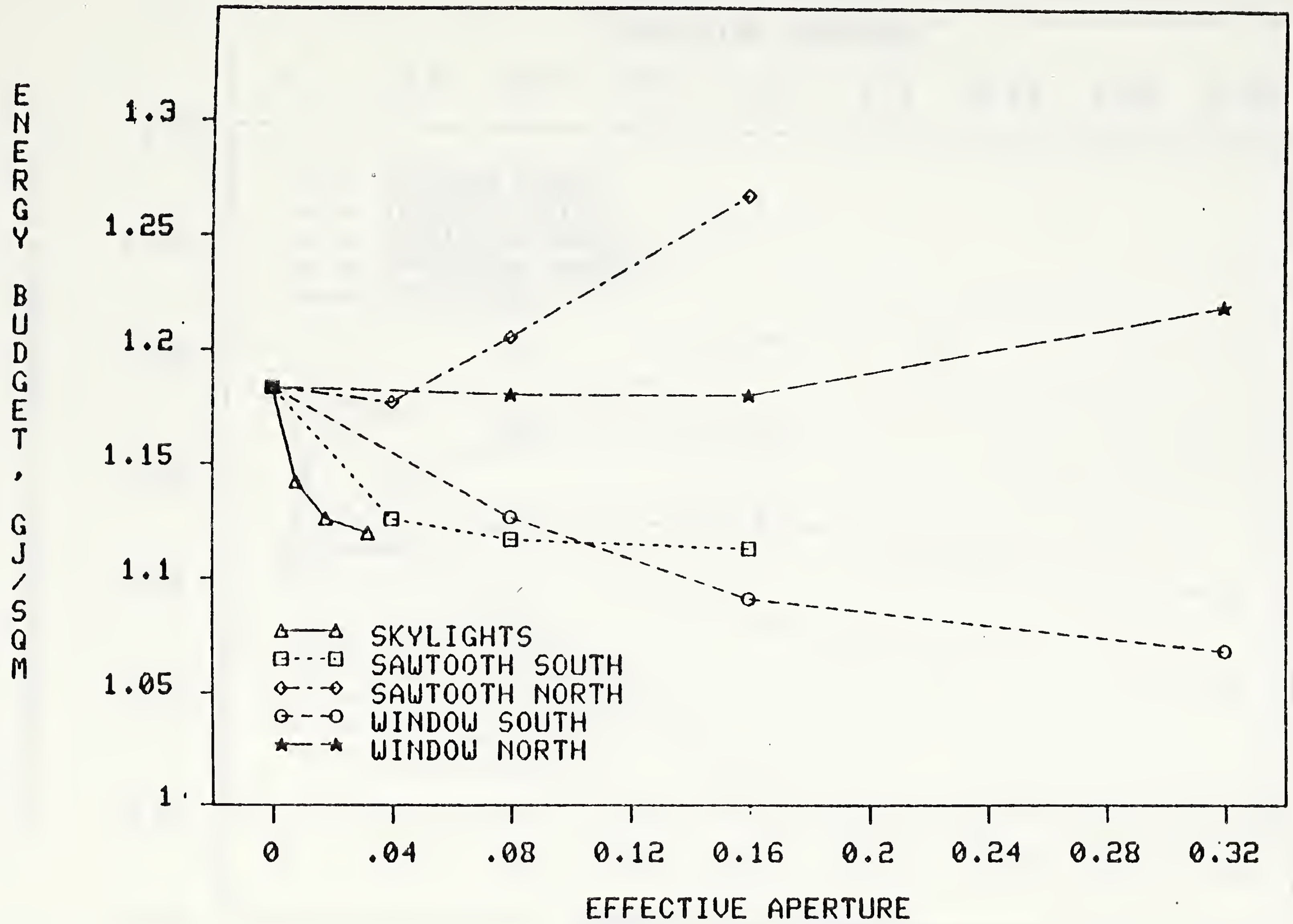


Figure 236. TOTAL ENERGY WITH DAYLIGHT (Boston)
BRICK ATTACHED



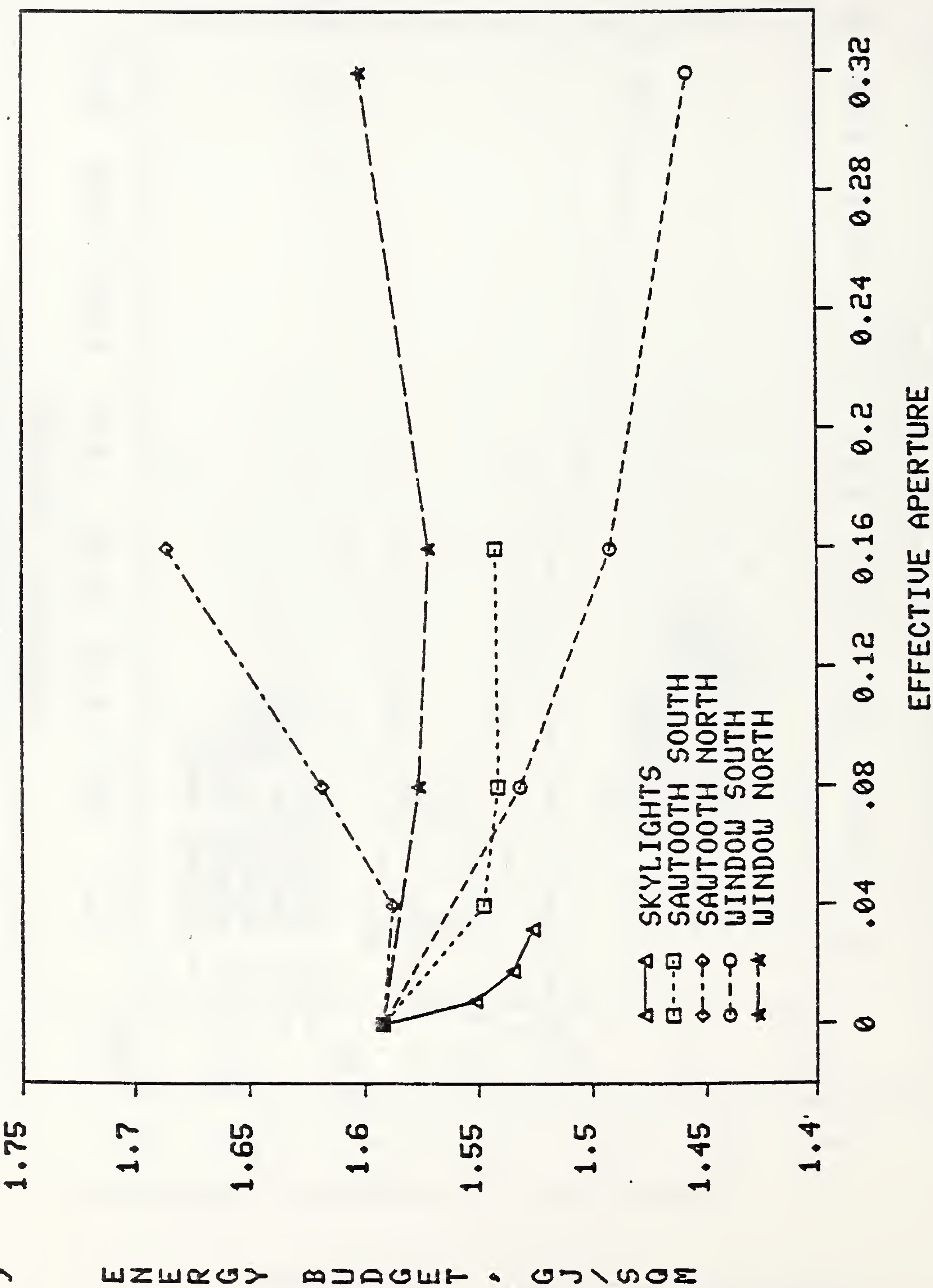



Figure 237. TOTAL ENERGY WITH DAYLIGHT (Boston)
METAL FREESTANDING

Figure 238. TOTAL ENERGY WITH DAYLIGHT (Boston)
METAL ATTACHED

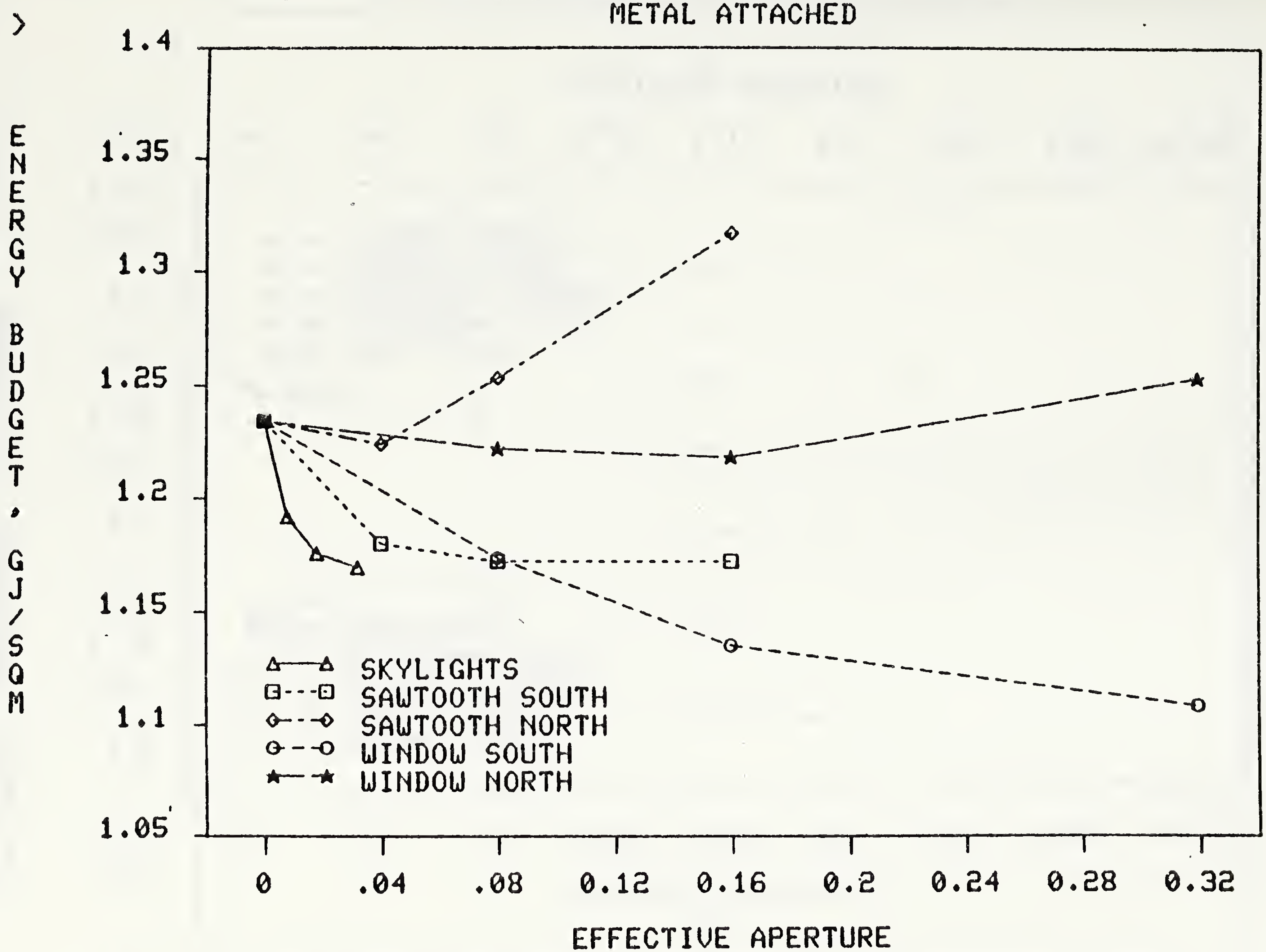


Figure 239. TOTAL ENERGY WITHOUT DAYLIGHT (Boston)
BRICK FREESTANDING

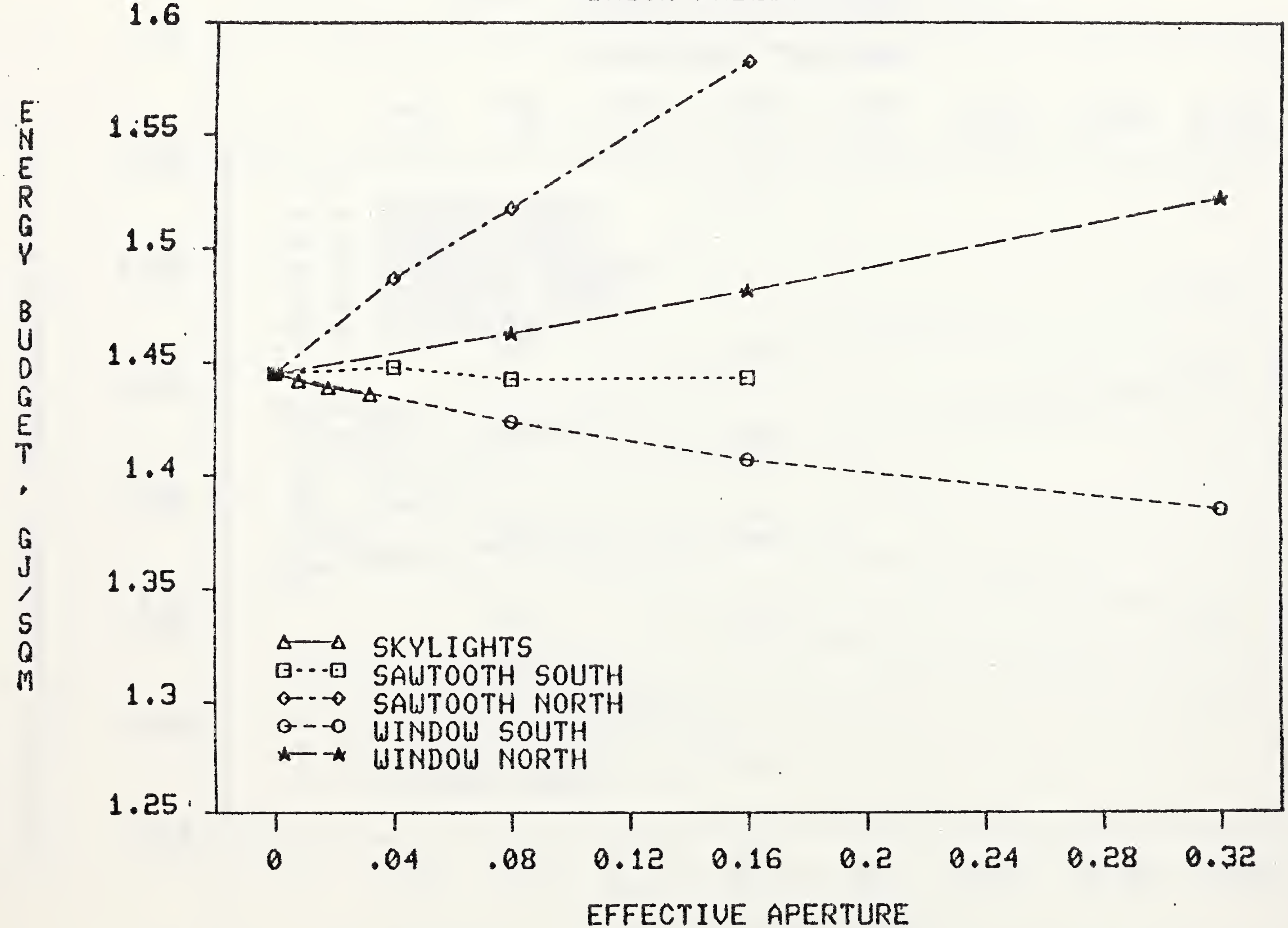


Figure 240. TOTAL ENERGY WITHOUT DAYLIGHT (Boston) BRICK ATTACHED

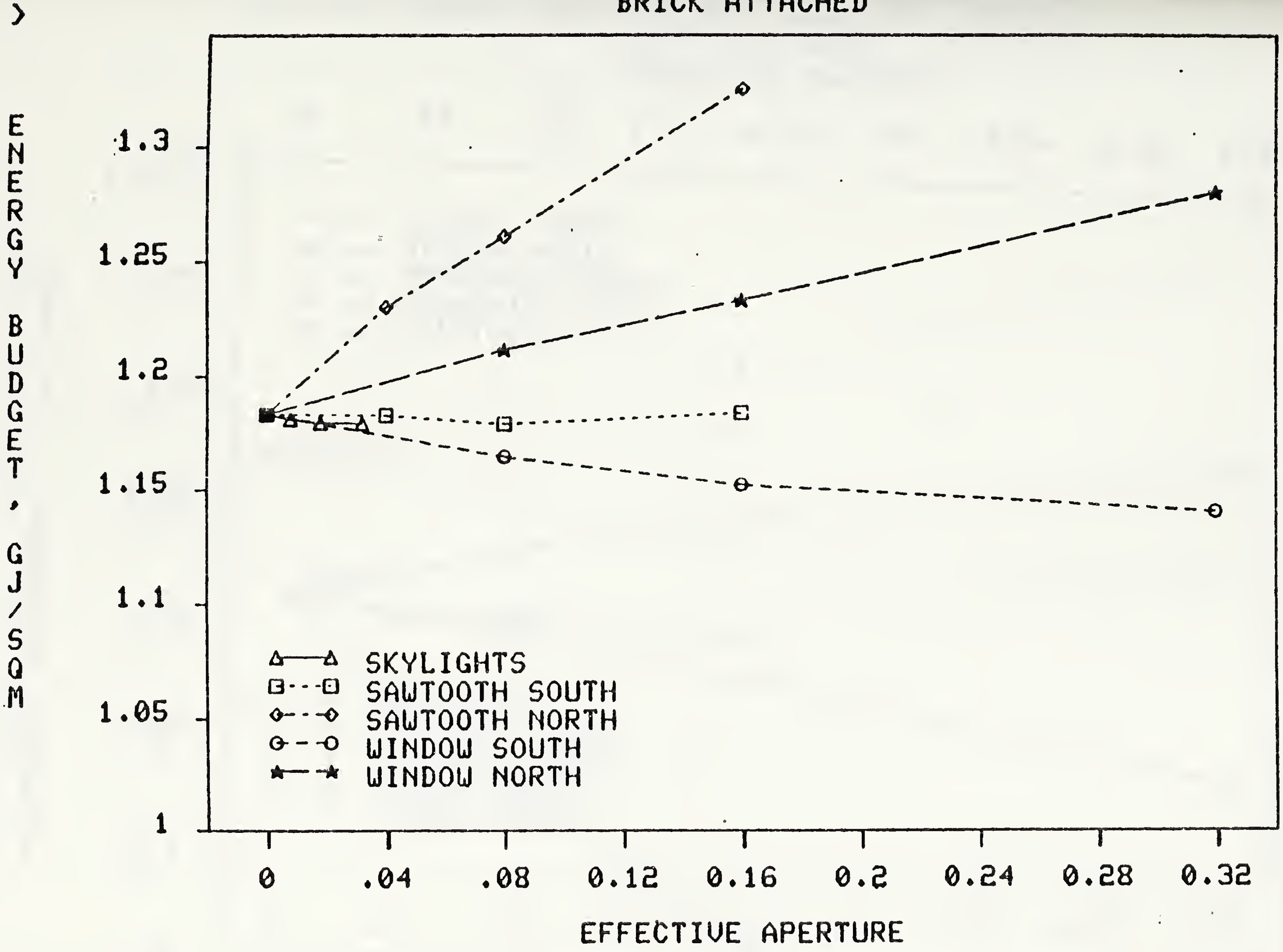


Figure 241. TOTAL ENERGY WITHOUT DAYLIGHT (Boston)
METAL FREESTANDING

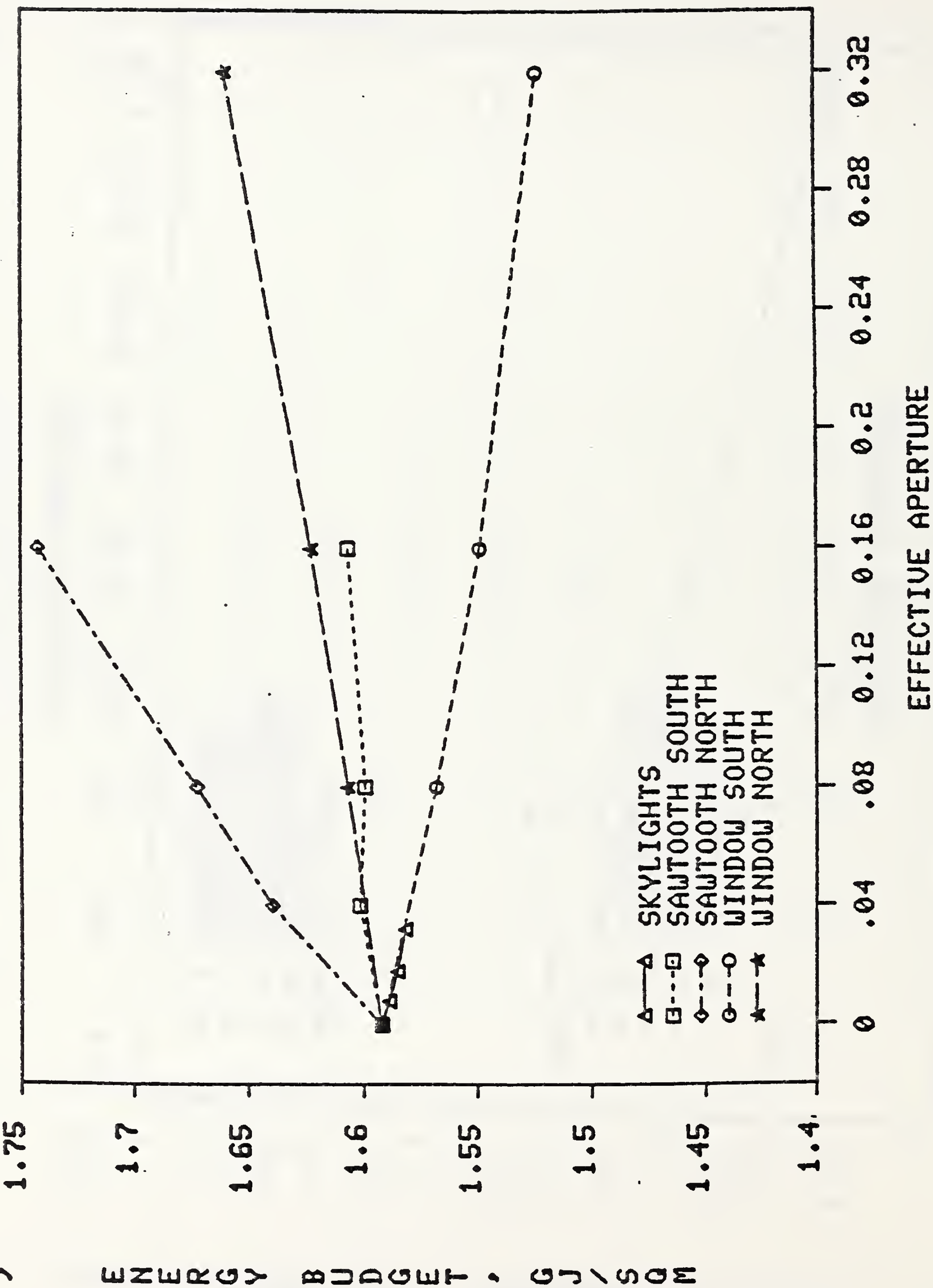


Figure 242. TOTAL ENERGY WITHOUT DAYLIGHT (Boston)
METAL ATTACHED

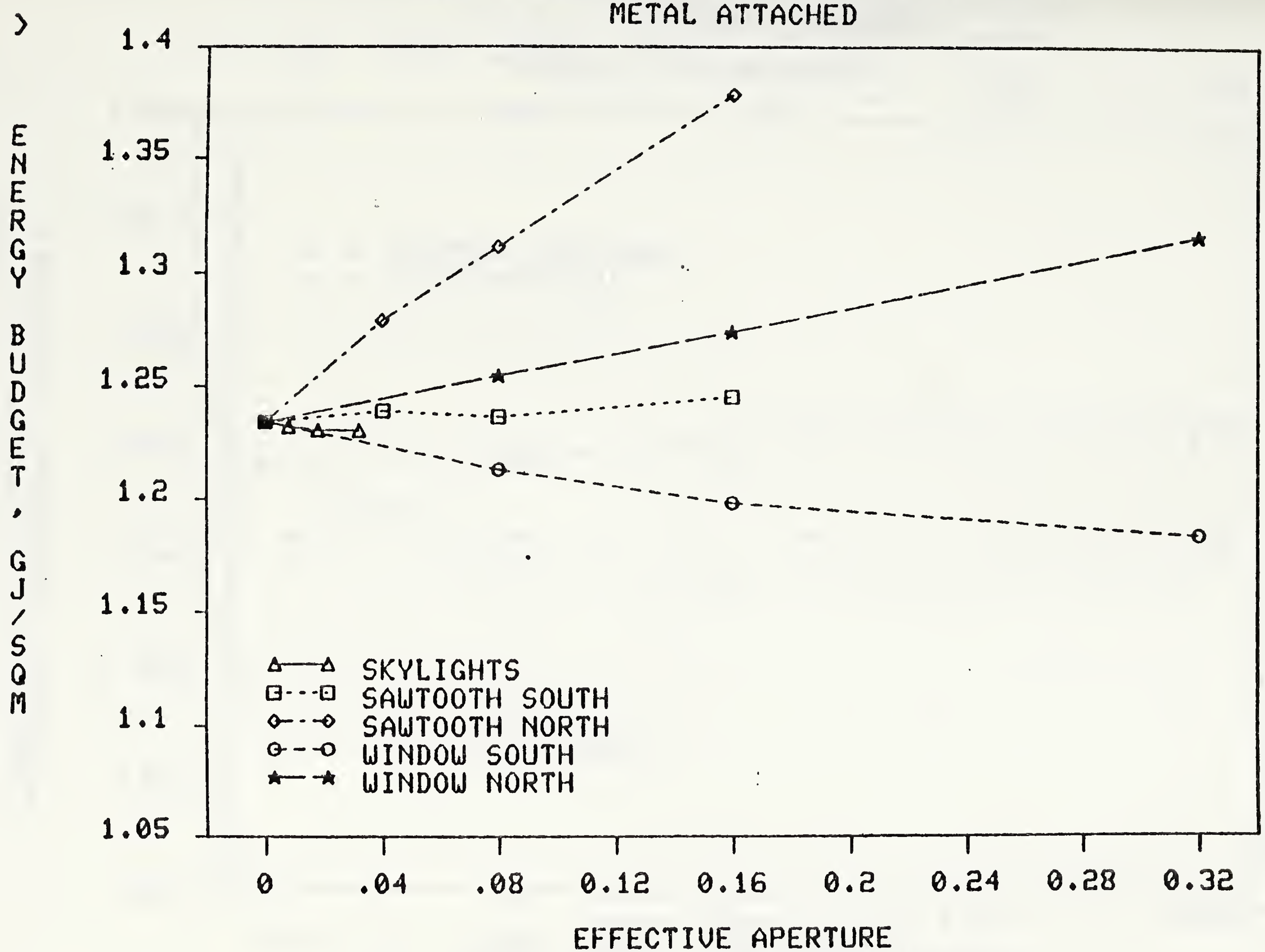


Figure 243. TOTAL ENERGY - SKYLIGHTS (Boston) BRICK FREESTANDING

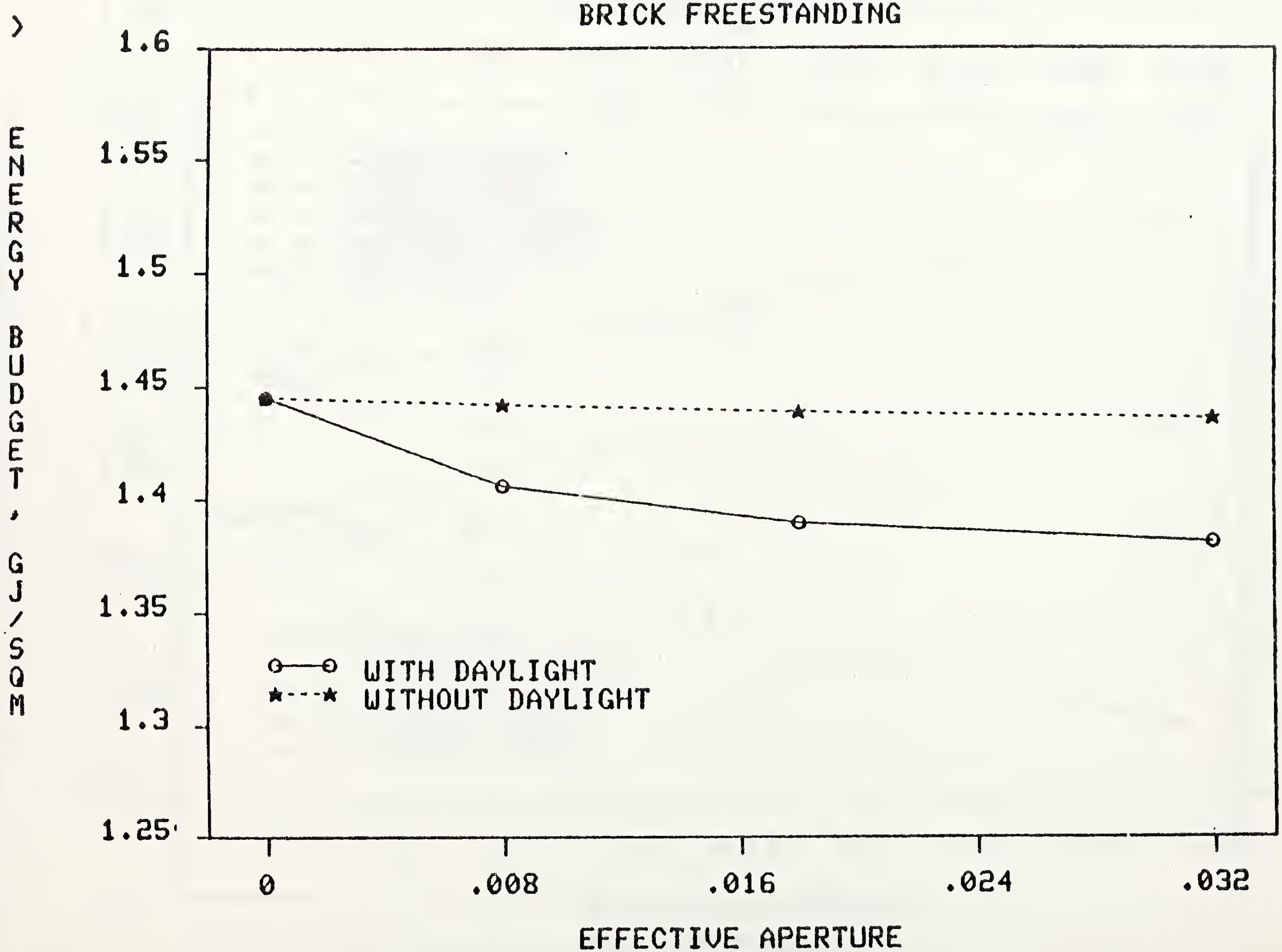


Figure 244. TOTAL ENERGY - SOUTH SAWTOOTH (Boston)
BRICK FREESTANDING

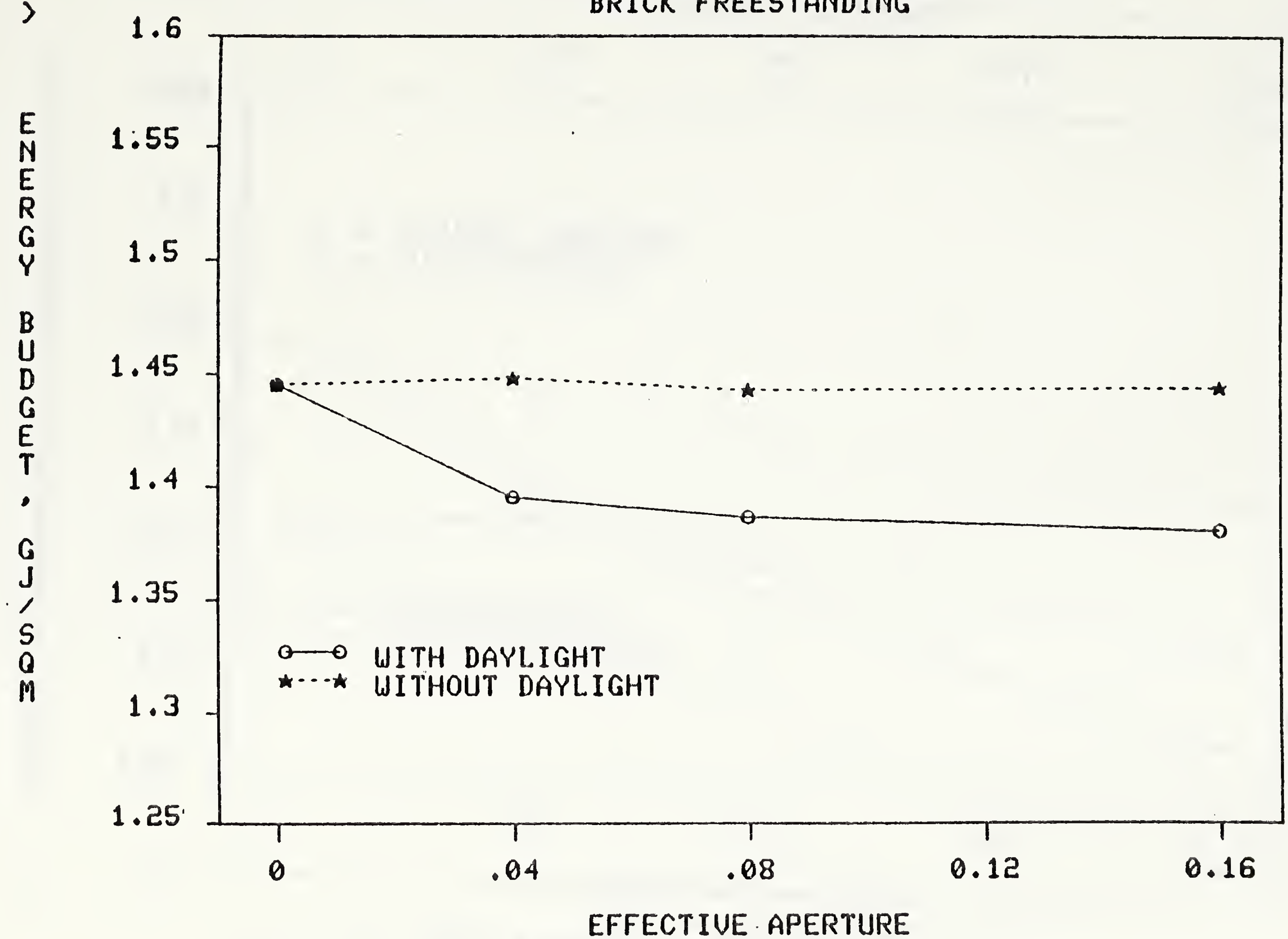


Figure 245. TOTAL ENERGY - NORTH SAWTOOTH (Boston)
BRICK FREESTANDING

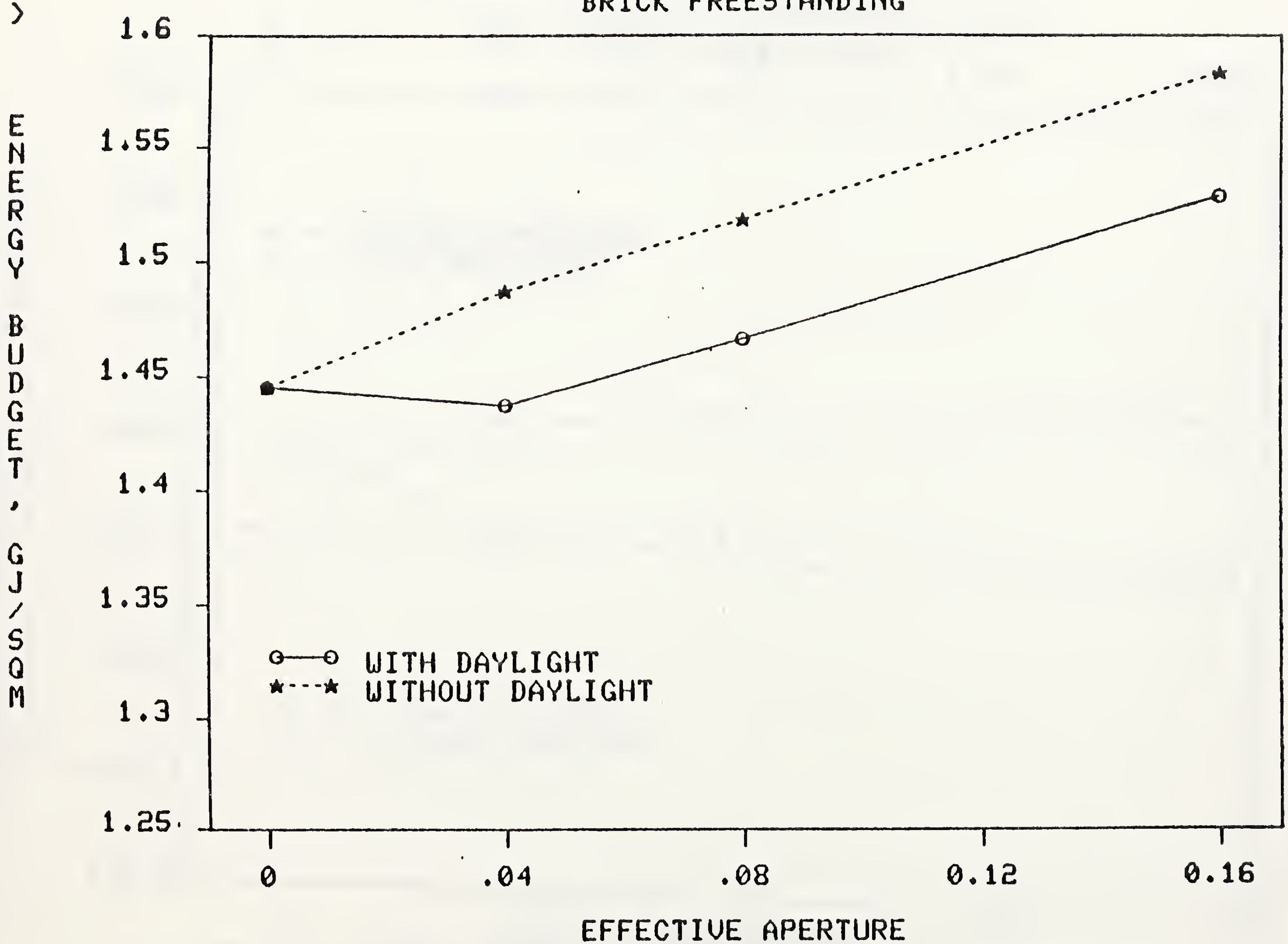


Figure 246. TOTAL ENERGY - SOUTH WINDOW (Boston)
BRICK FREESTANDING

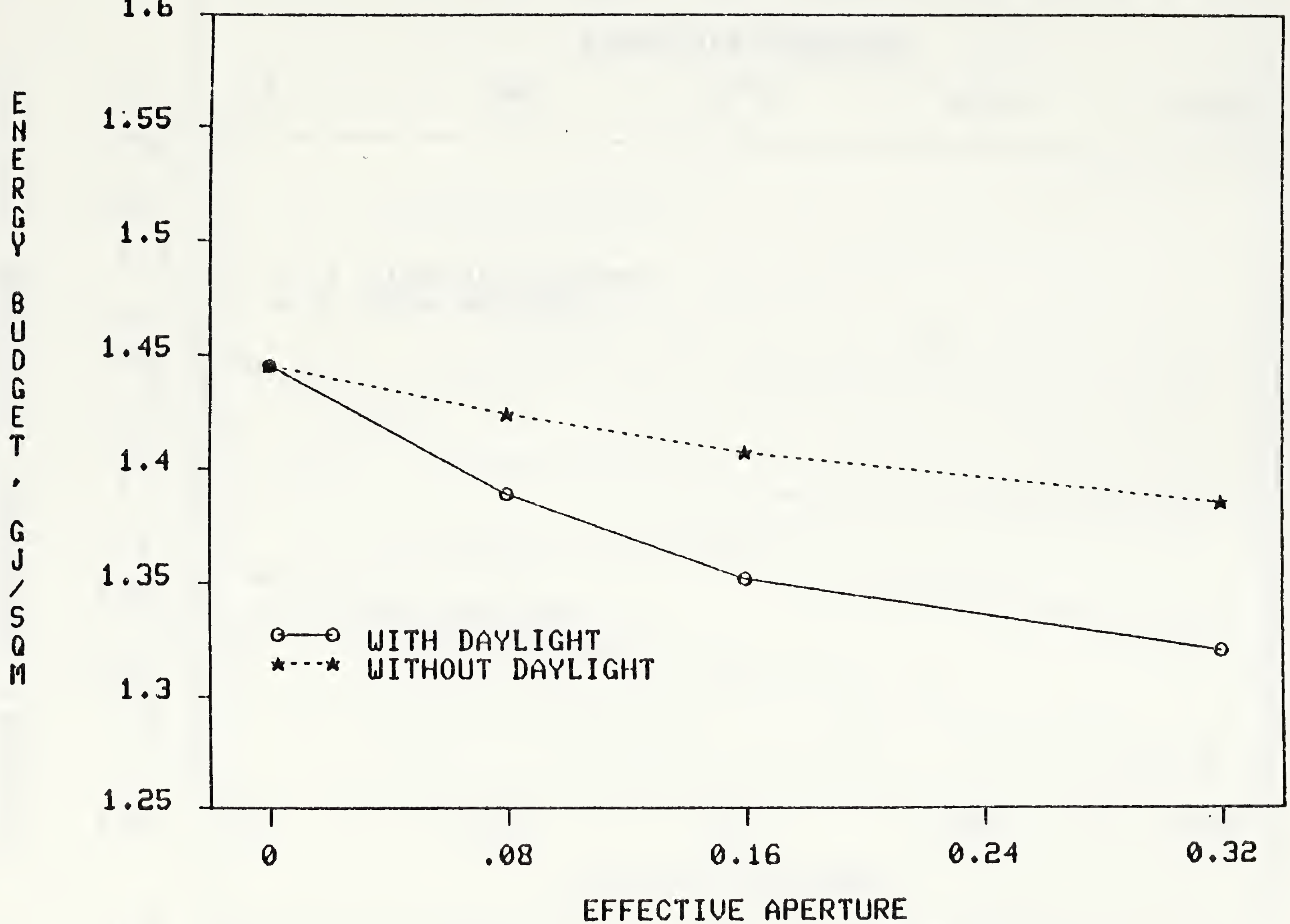


Figure 247. TOTAL ENERGY - NORTH WINDOW (Boston)
BRICK FREESTANDING

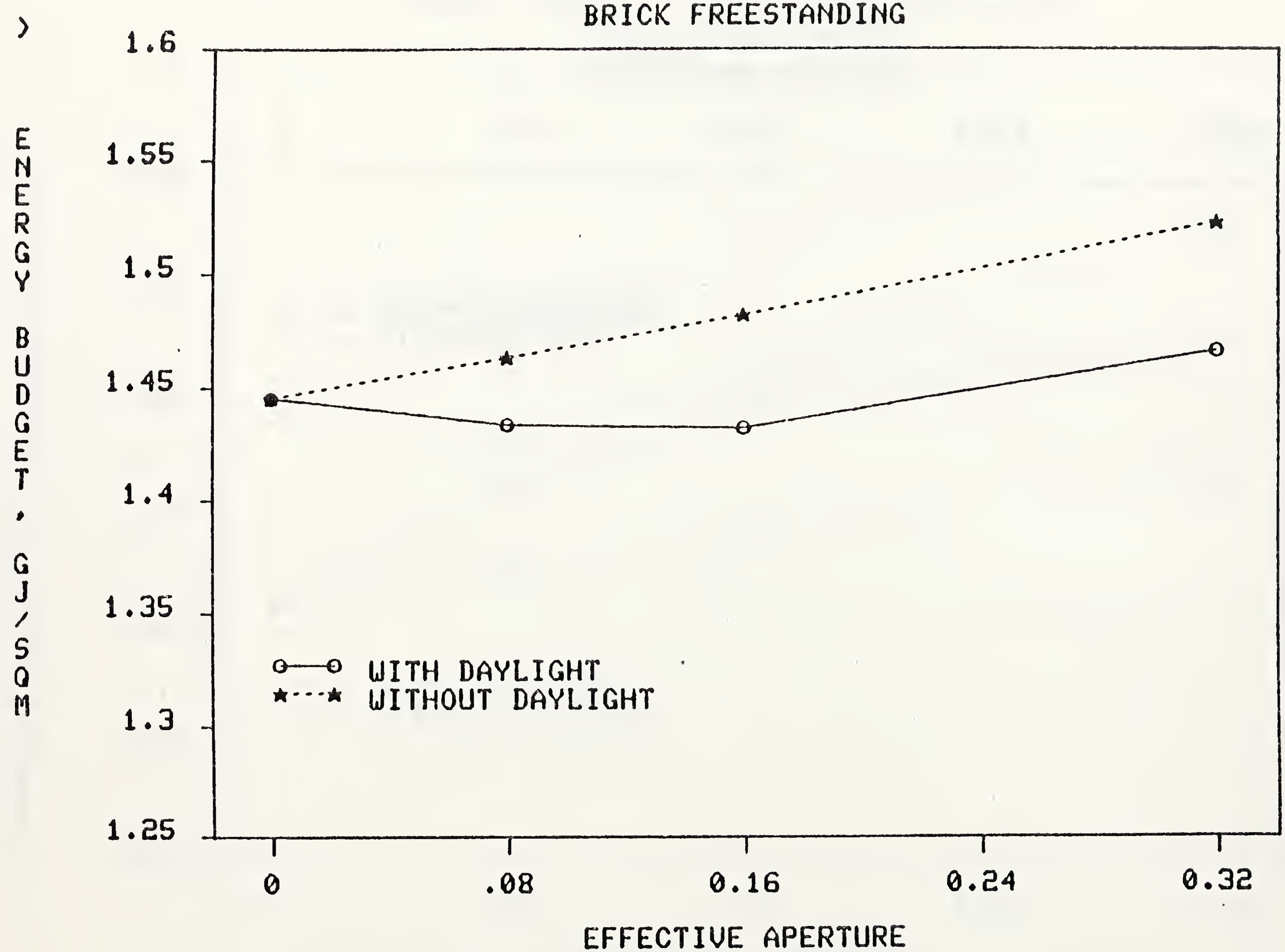


Figure 248. TOTAL ENERGY - SKYLIGHTS (Boston)
BRICK ATTACHED

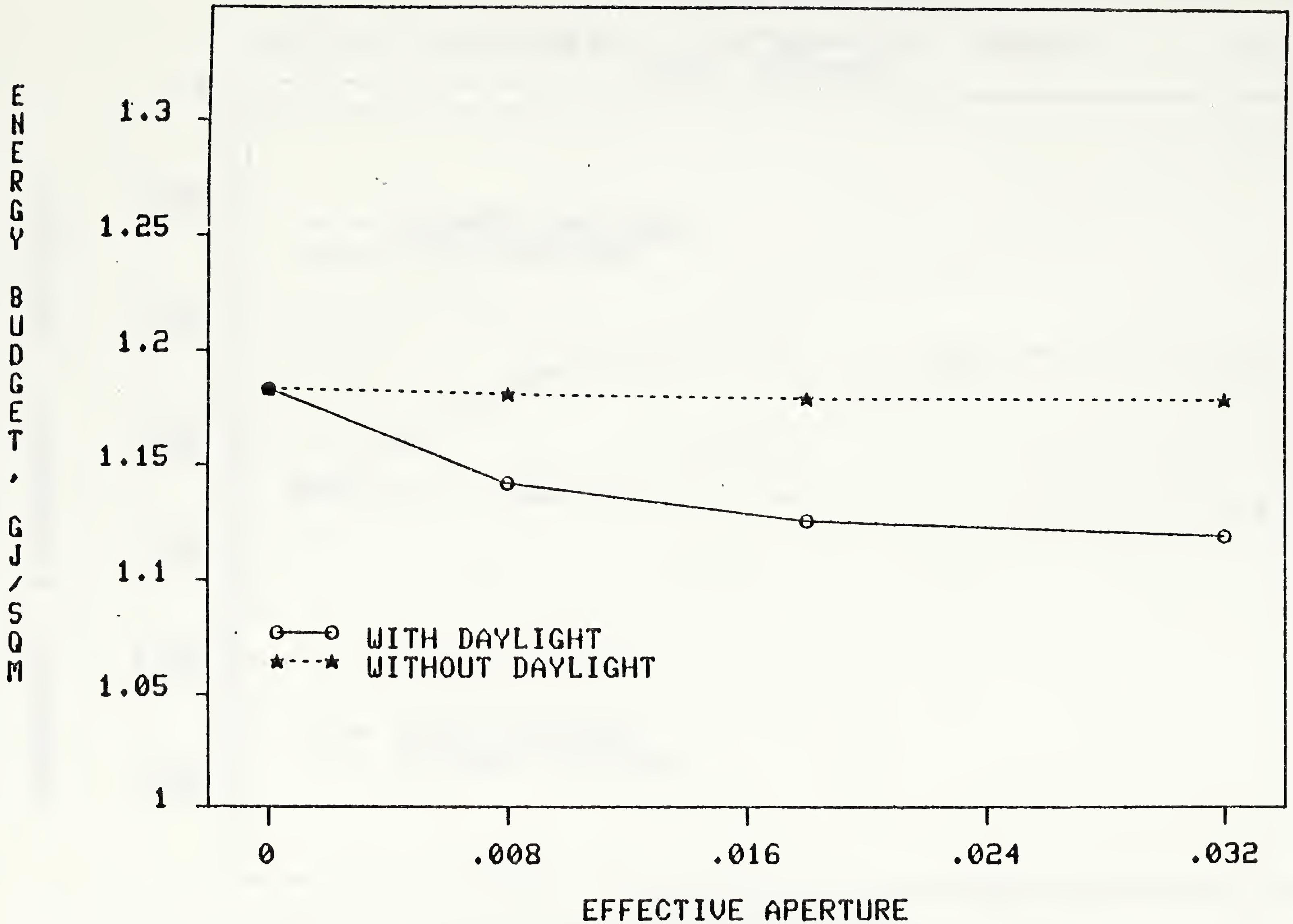


Figure 249. TOTAL ENERGY - SOUTH SAWTOOTH (Boston)
BRICK ATTACHED

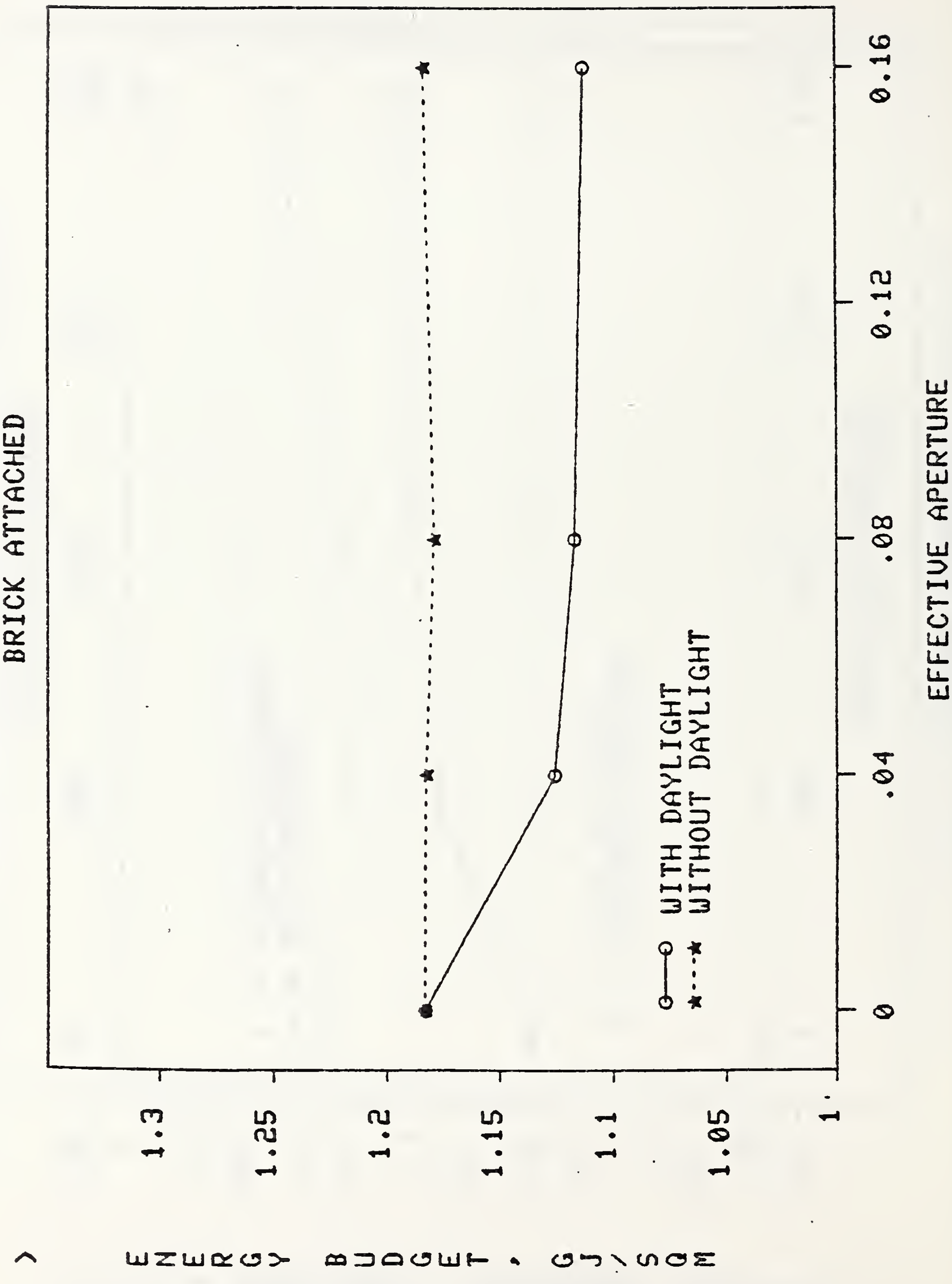


Figure 250. TOTAL ENERGY - NORTH SAWTOOTH (Boston)
BRICK ATTACHED

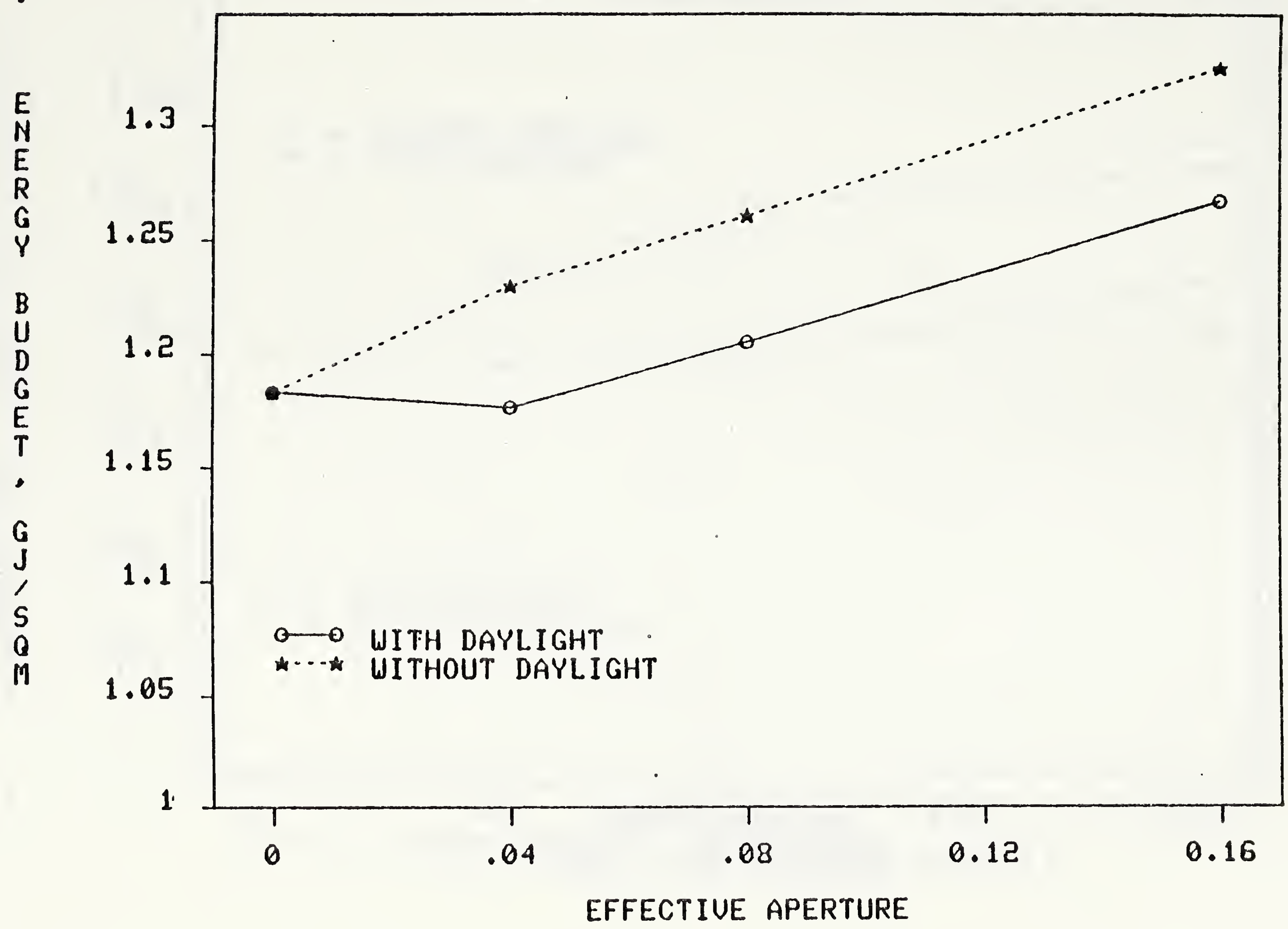


Figure 251. TOTAL ENERGY - SOUTH WINDOW (Boston)
BRICK ATTACHED

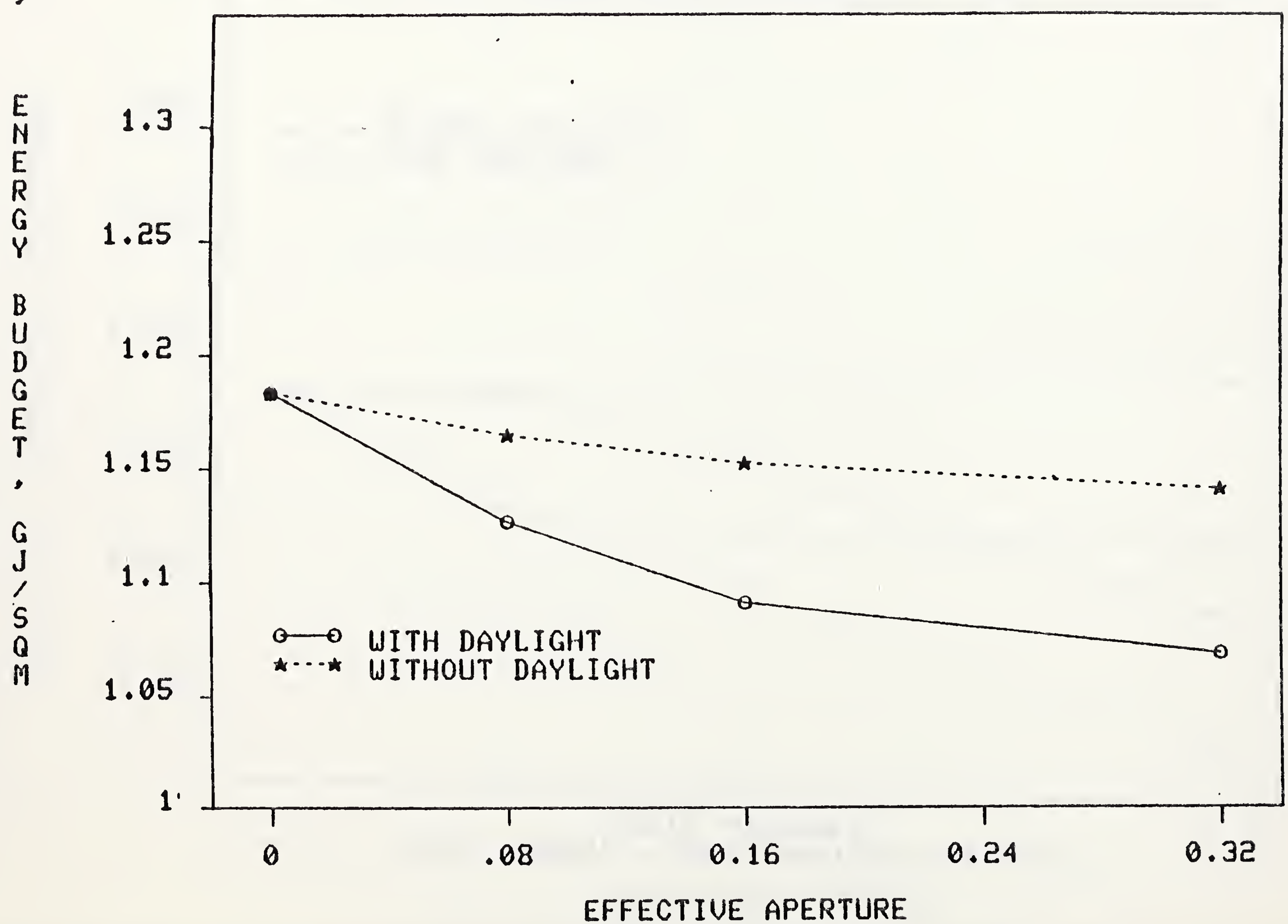


Figure 252. TOTAL ENERGY - NORTH WINDOW (Boston) BRICK ATTACHED

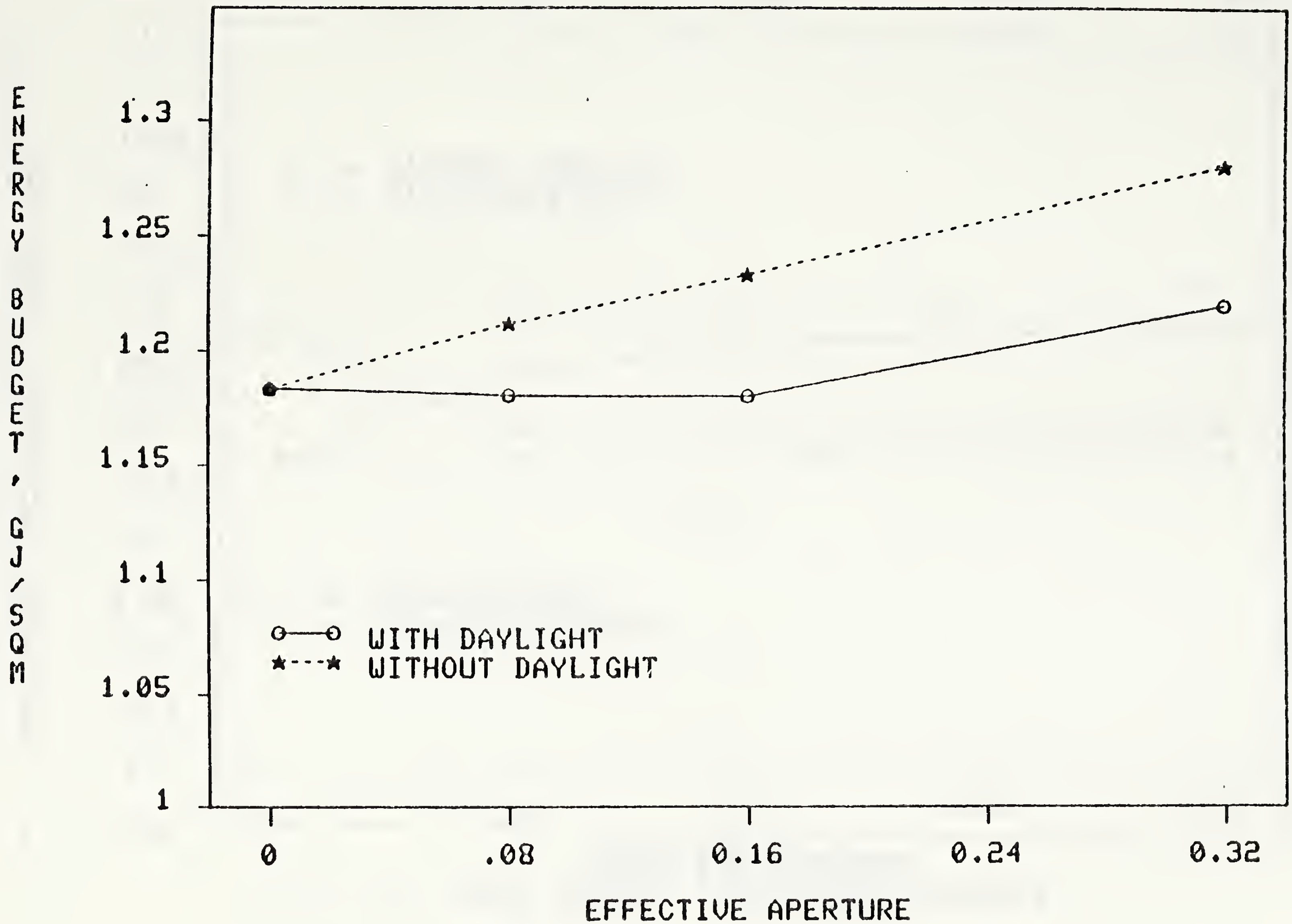


Figure 253. TOTAL ENERGY - SKYLIGHTS (Boston)
METAL FREESTANDING

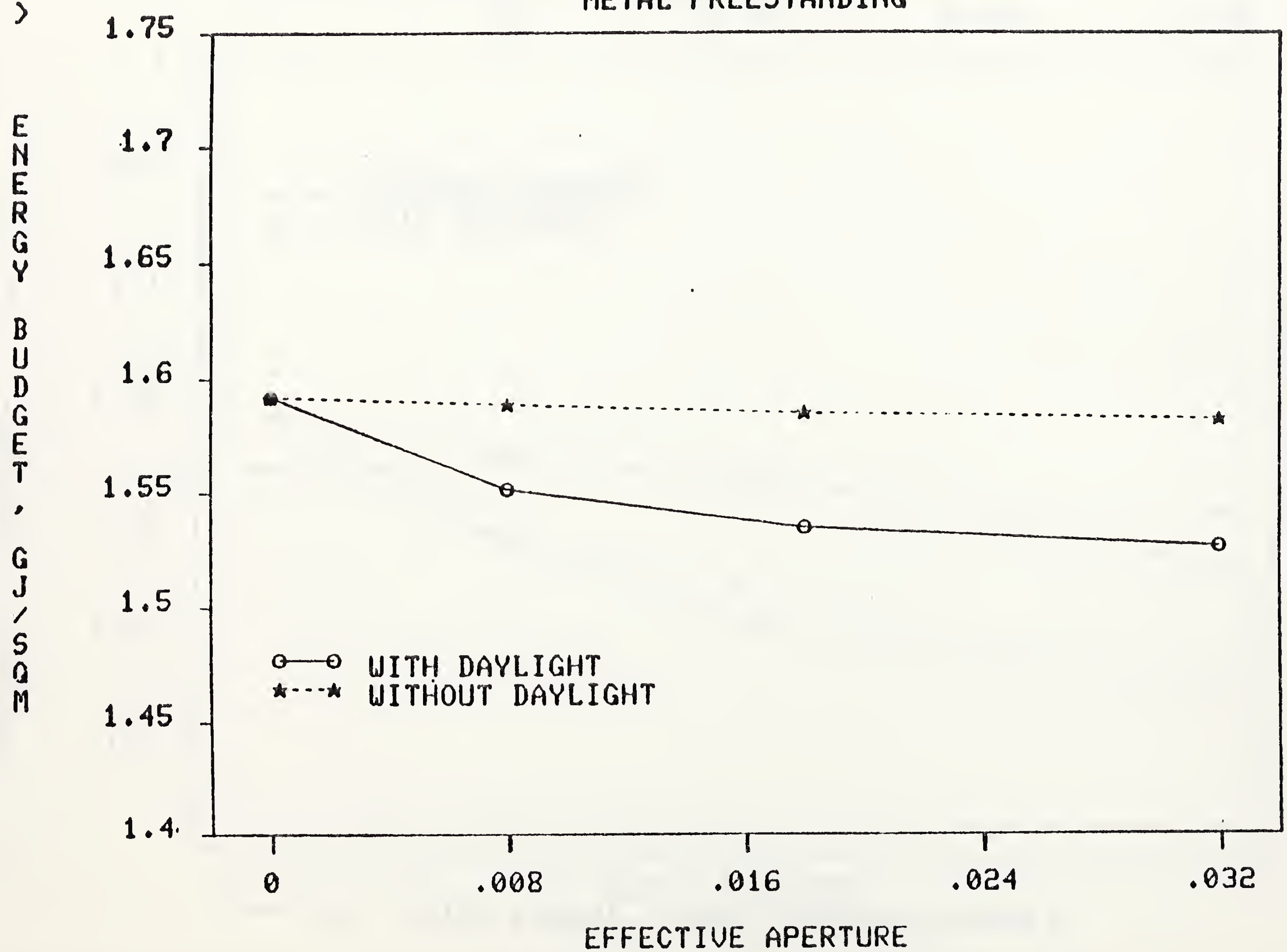


Figure 254. TOTAL ENERGY - SOUTH SAWTOOTH (Boston)
METAL FREESTANDING

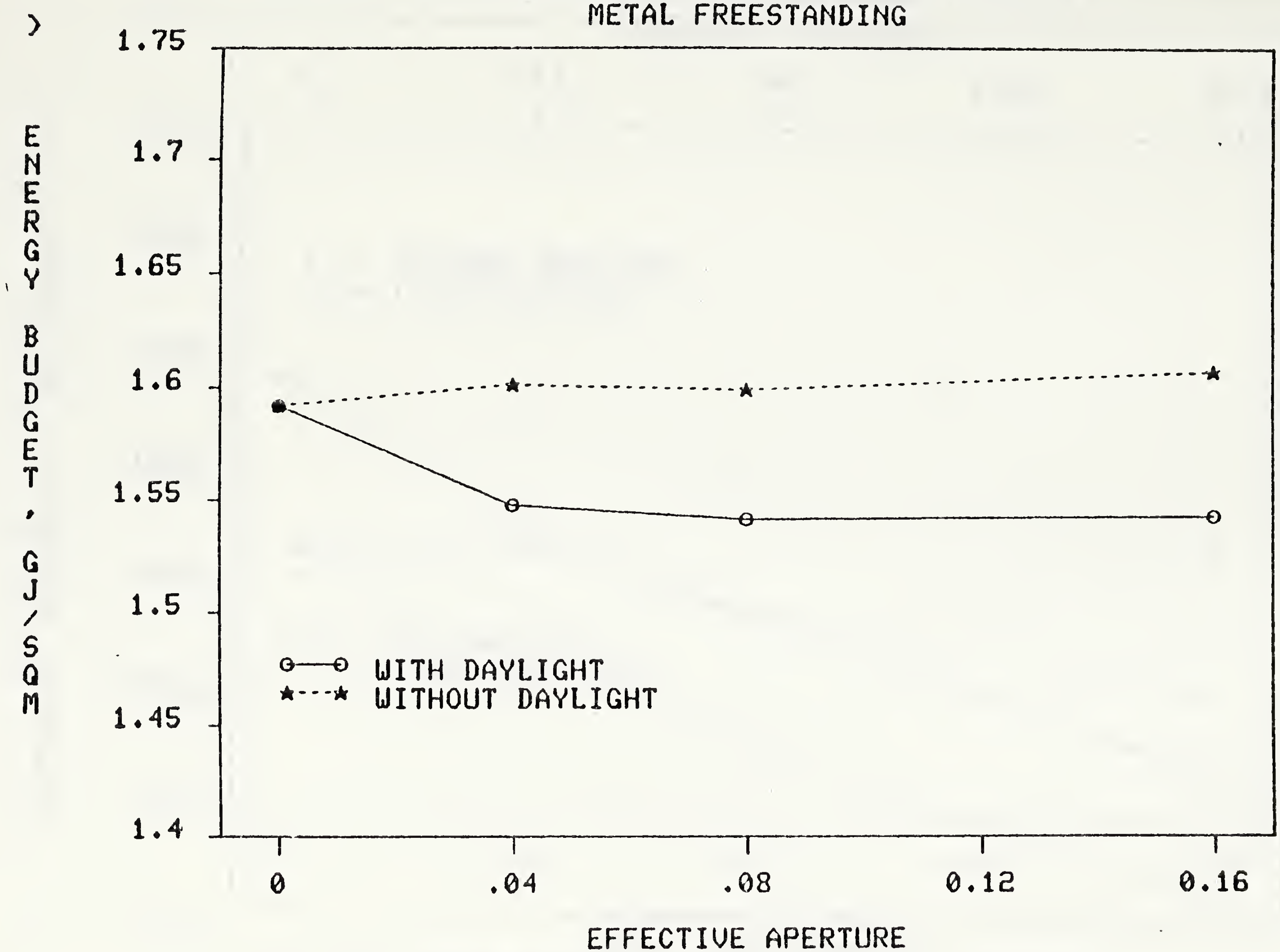


Figure 255. TOTAL ENERGY - NORTH SAWTOOTH (Boston)
METAL FREESTANDING

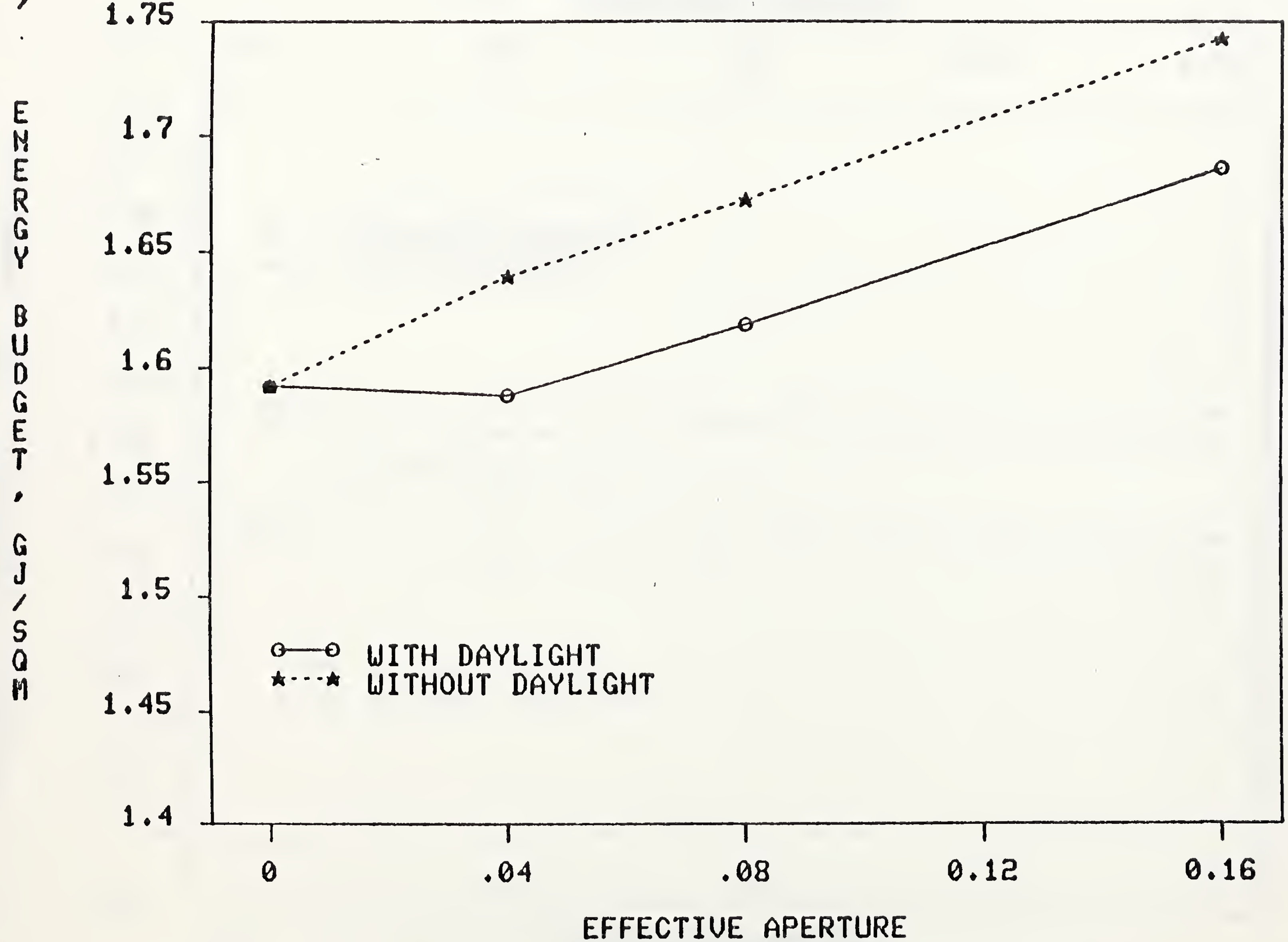


Figure 256. TOTAL ENERGY - SOUTH WINDOW (Boston)
METAL FREESTANDING

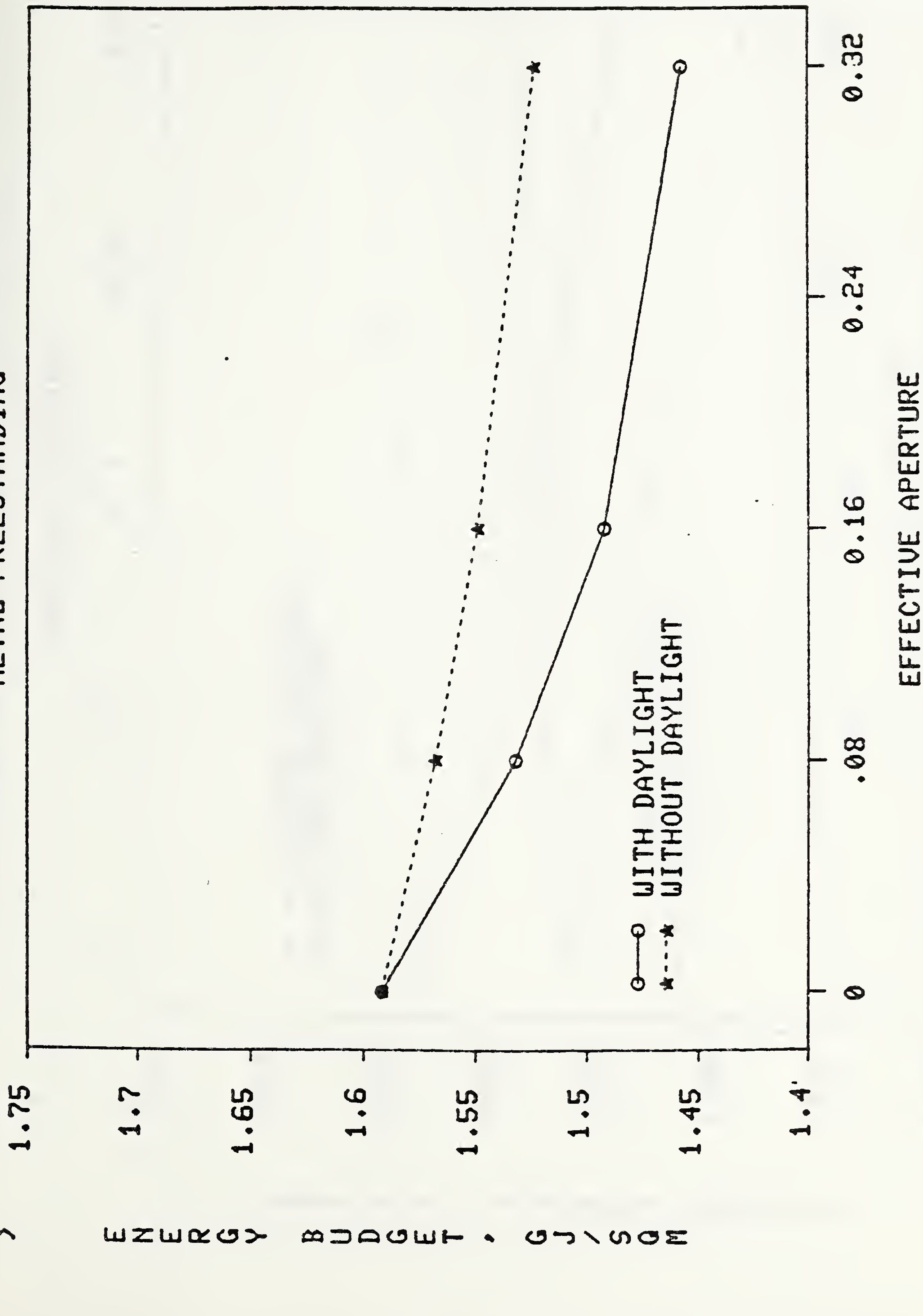


Figure 257. TOTAL ENERGY - NORTH WINDOW (Boston)
METAL FREESTANDING

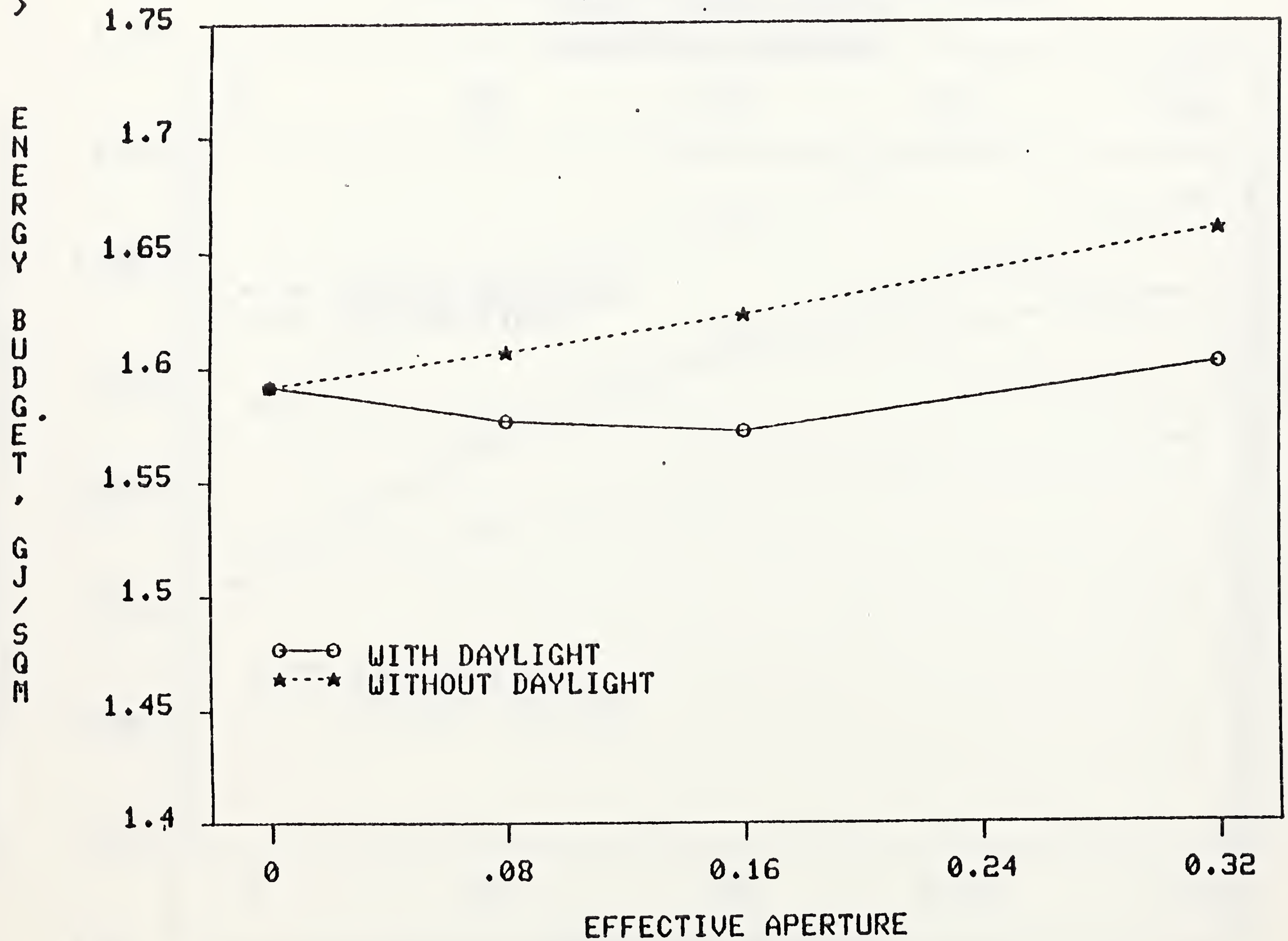


Figure 258. TOTAL ENERGY - SKYLIGHTS (Boston) METAL ATTACHED

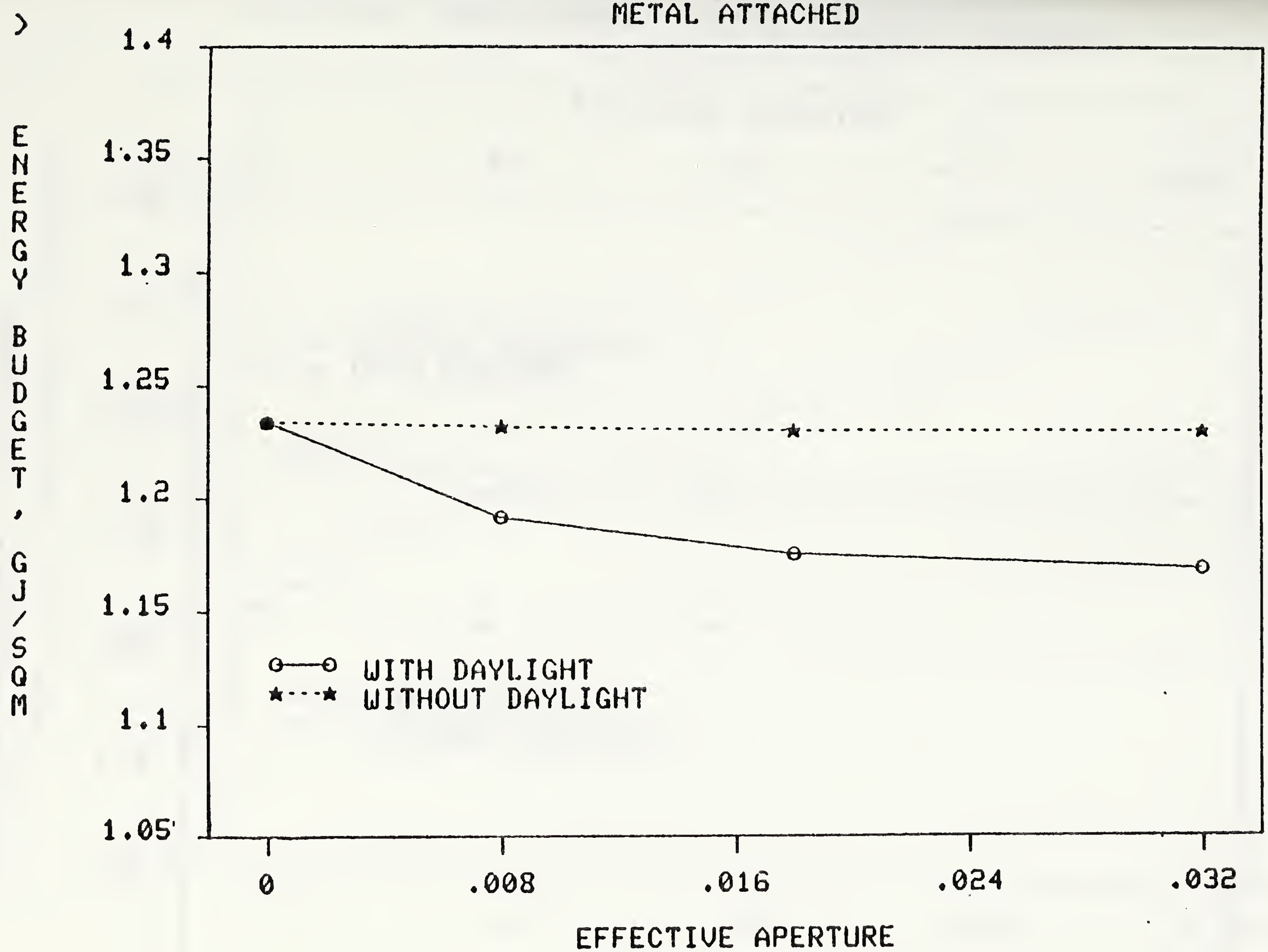


Figure 259. TOTAL ENERGY - SOUTH SAWTOOTH (Boston)
METAL ATTACHED

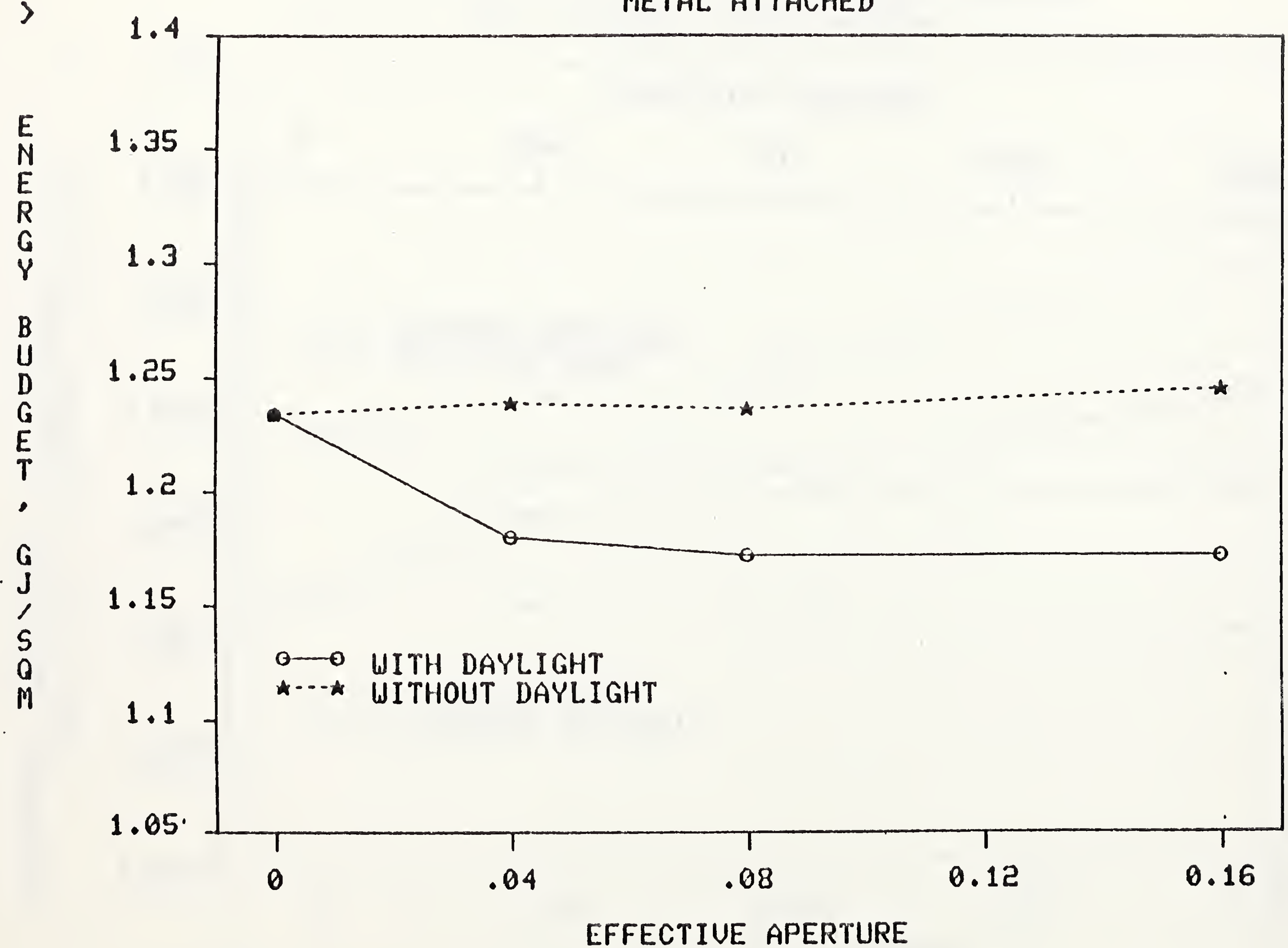


Figure 260. TOTAL ENERGY - NORTH SAWTOOTH (Boston)
METAL ATTACHED

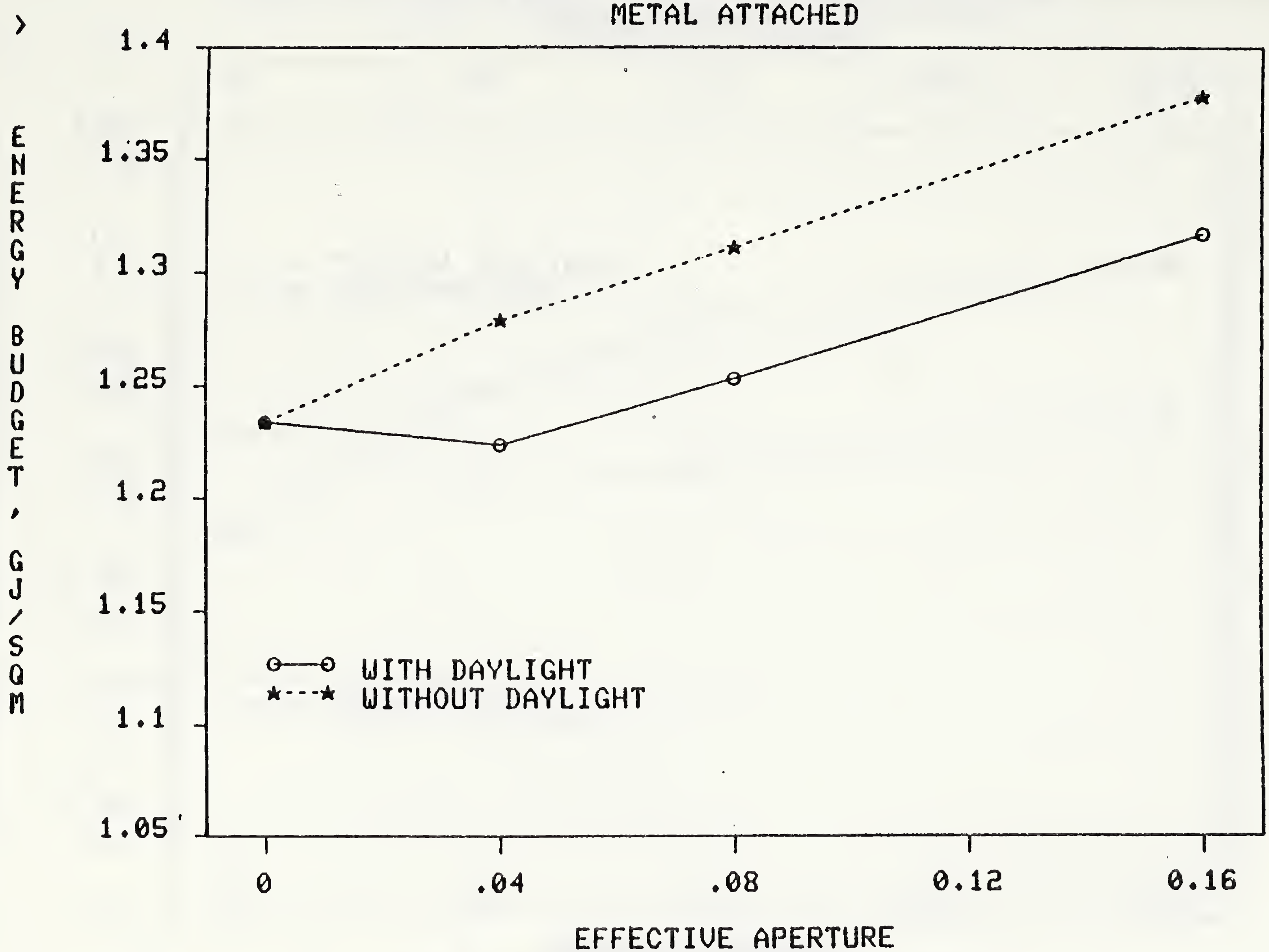


Figure 261. TOTAL ENERGY - SOUTH WINDOW (Boston)
METAL ATTACHED

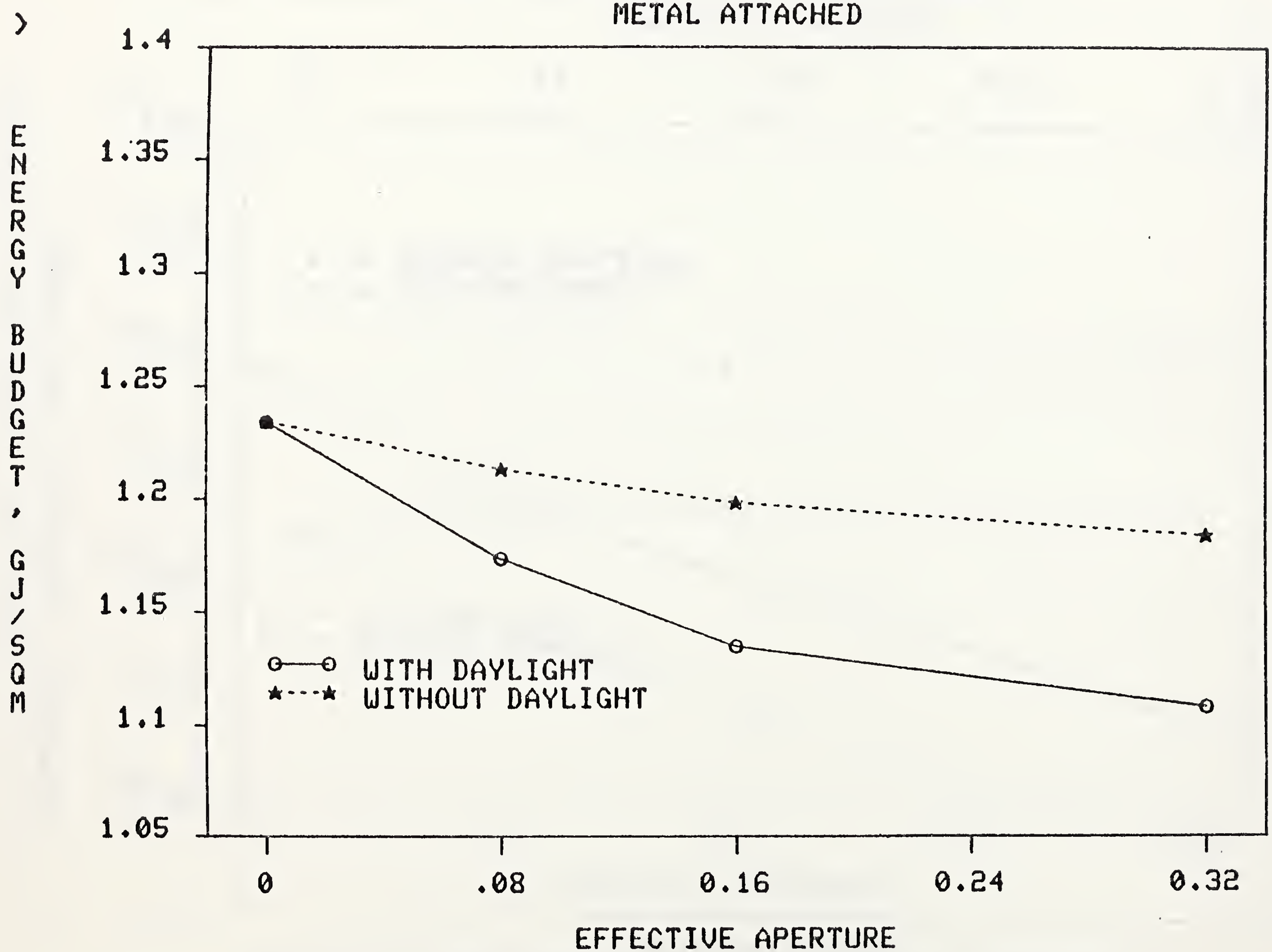


Figure 262. TOTAL ENERGY - NORTH WINDOW (Boston)
METAL ATTACHED

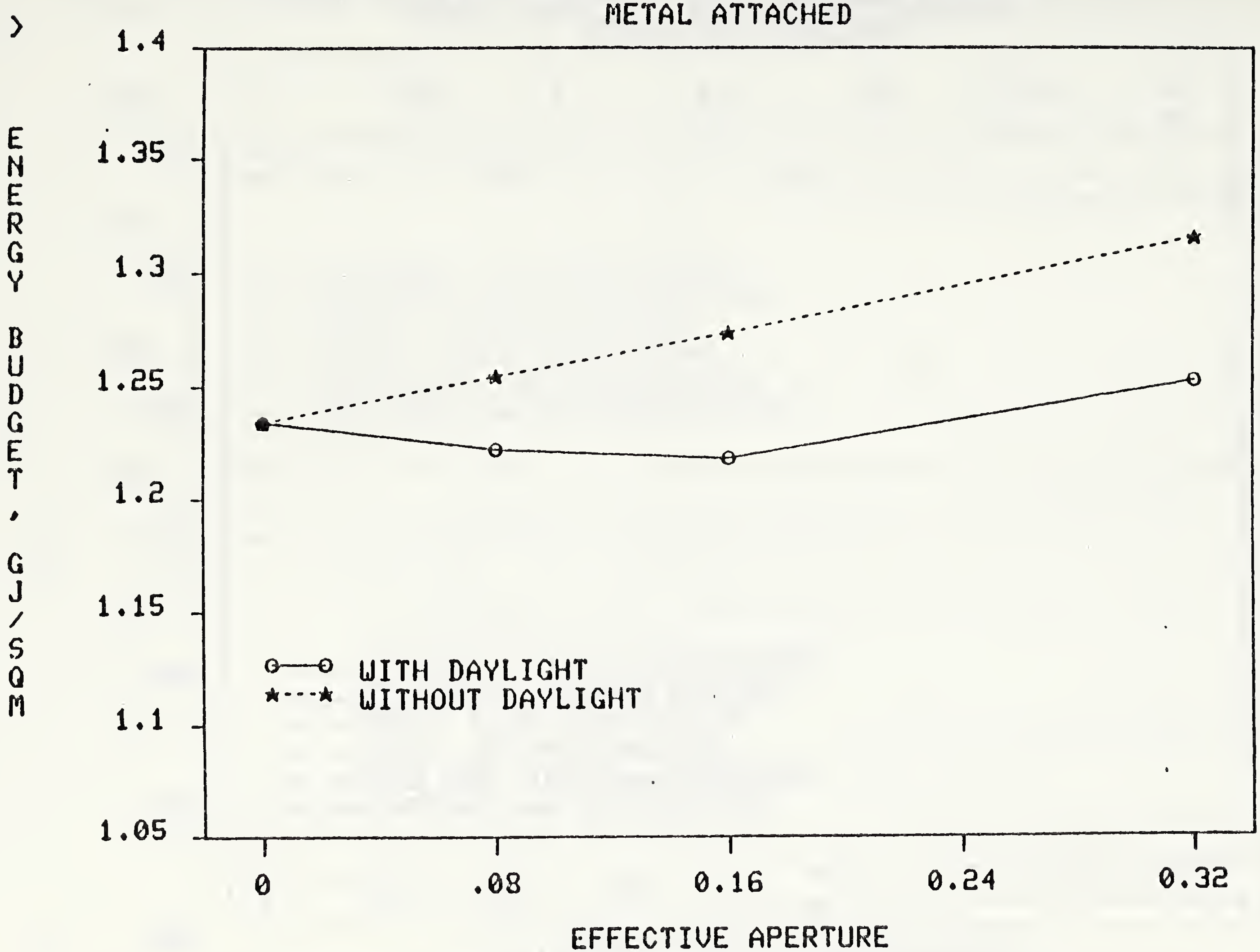


Figure 263. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston) SKYLIGHTS, BRICK FREESTANDING

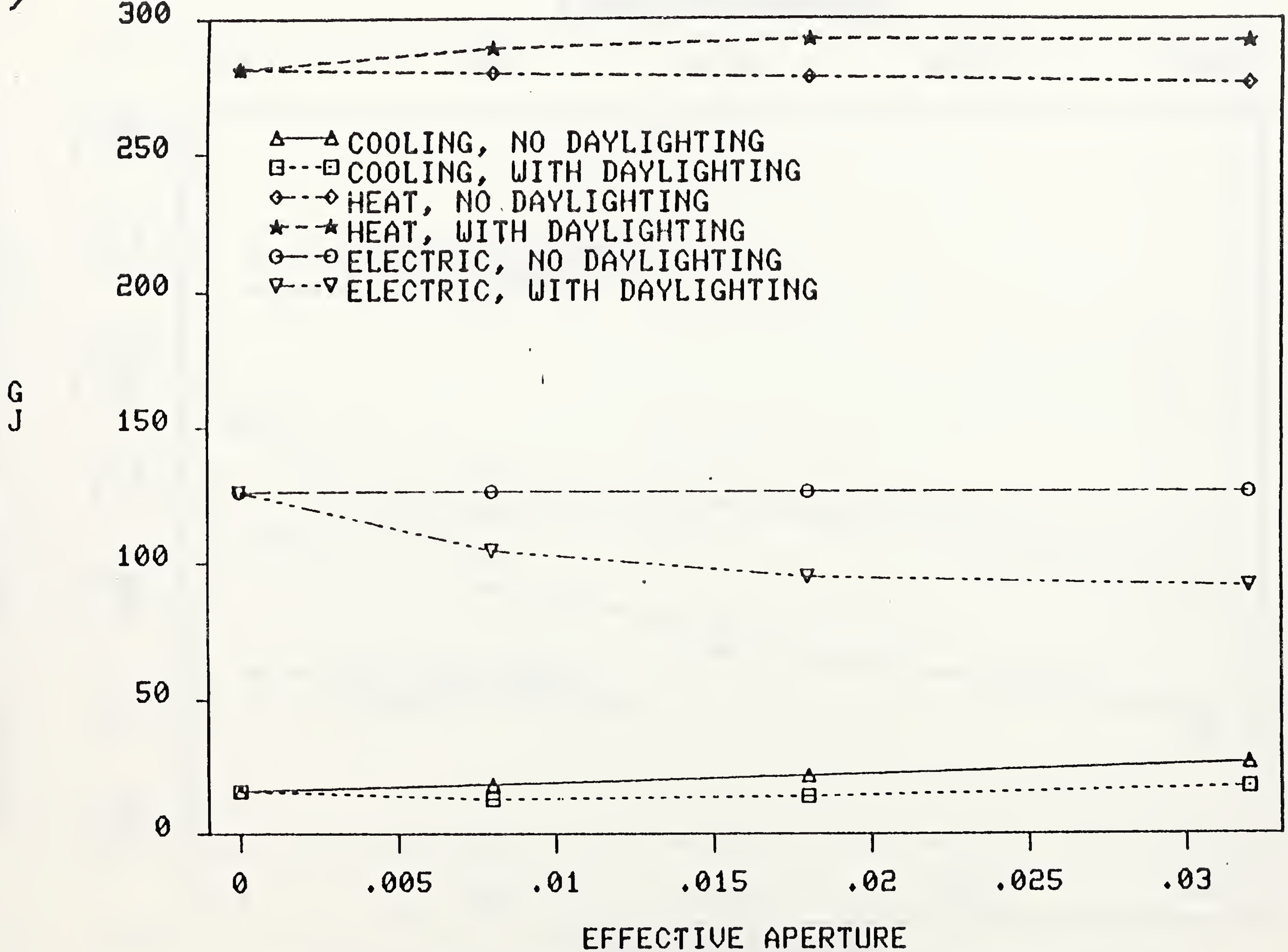


Figure 264. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston) SOUTH SAWTOOTH, BRICK FREESTANDING

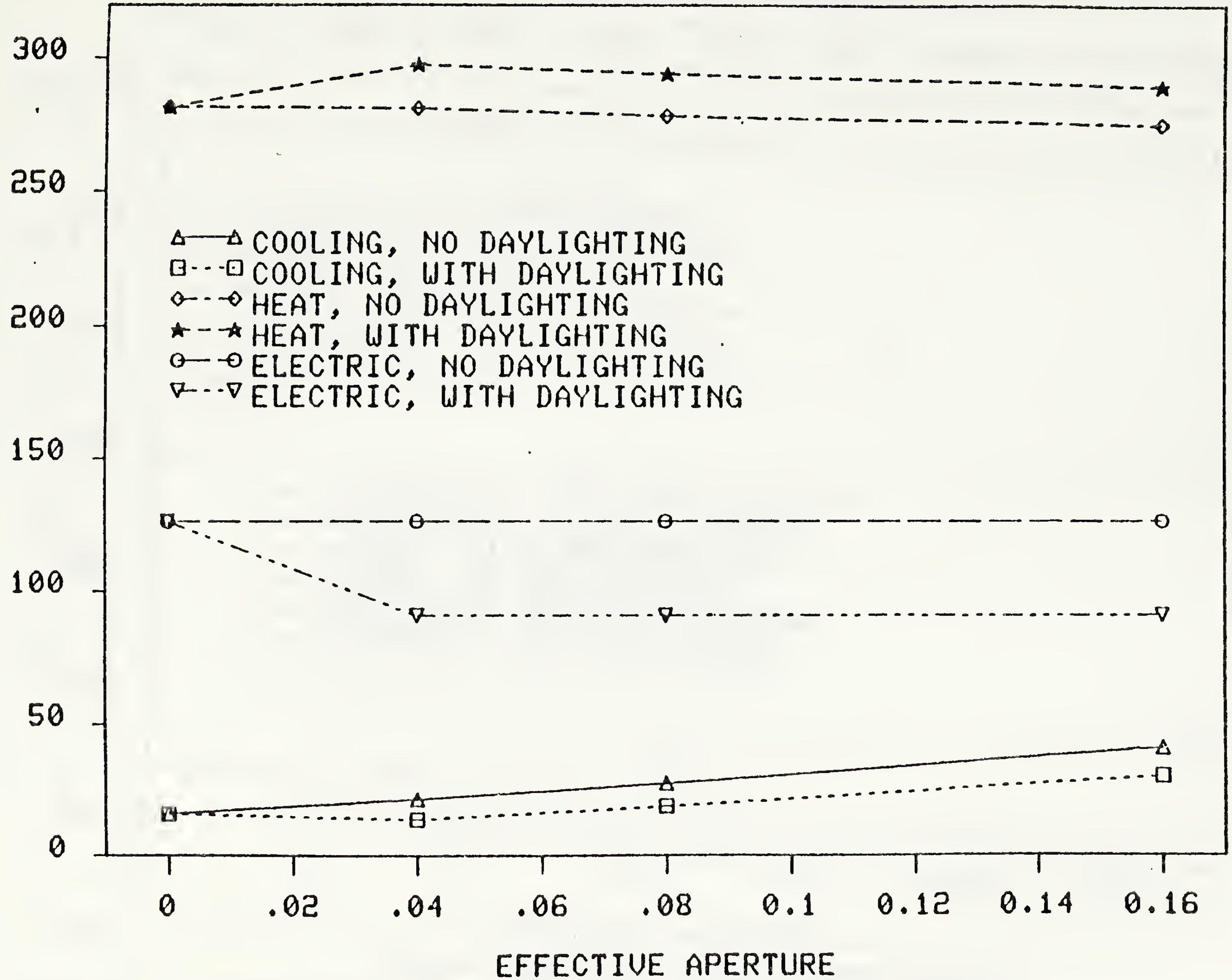


Figure 265. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
NORTH SAWTOOTH, BRICK FREESTANDING

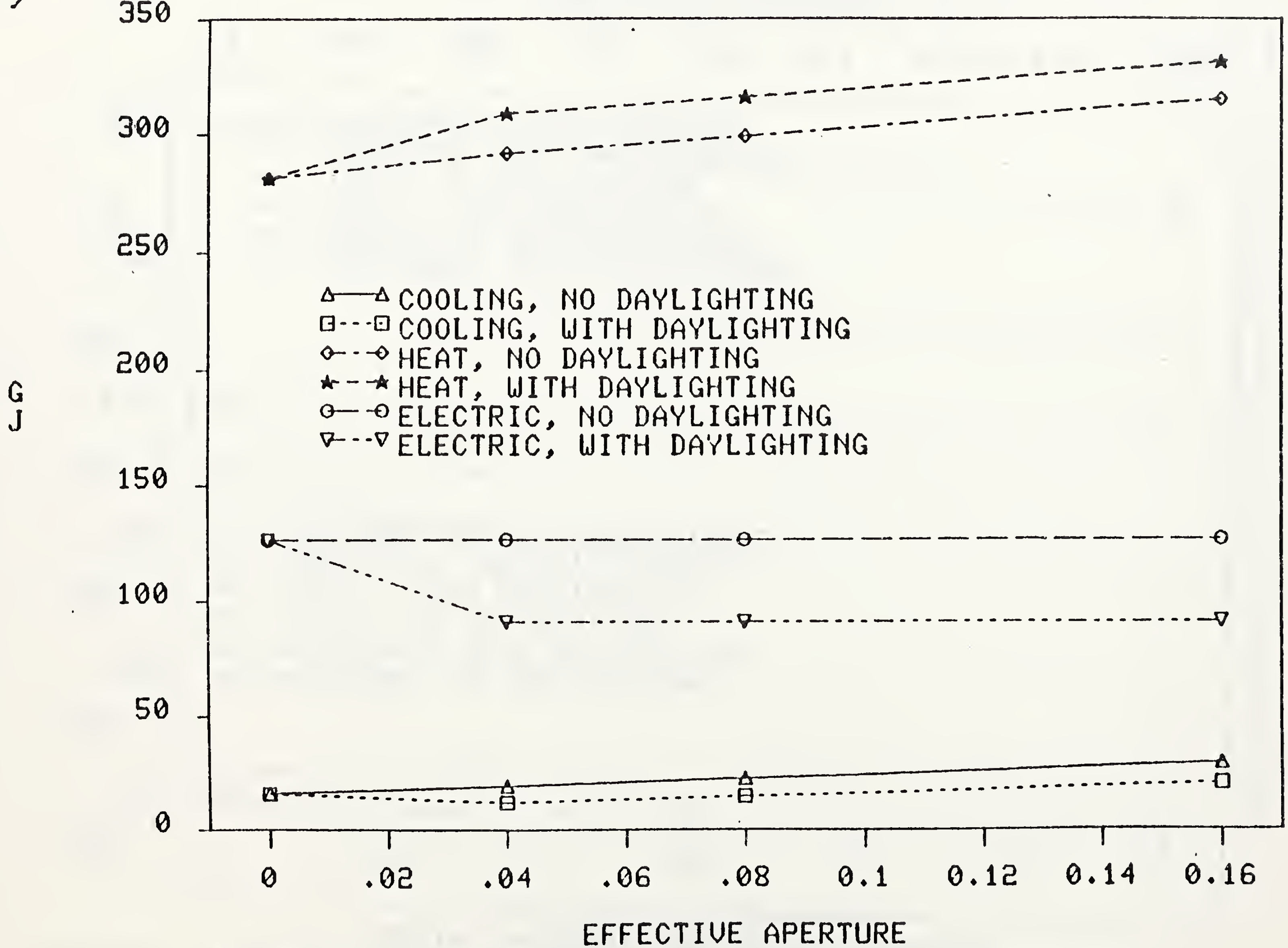


Figure 266. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston) SOUTH WINDOW, BRICK FREESTANDING

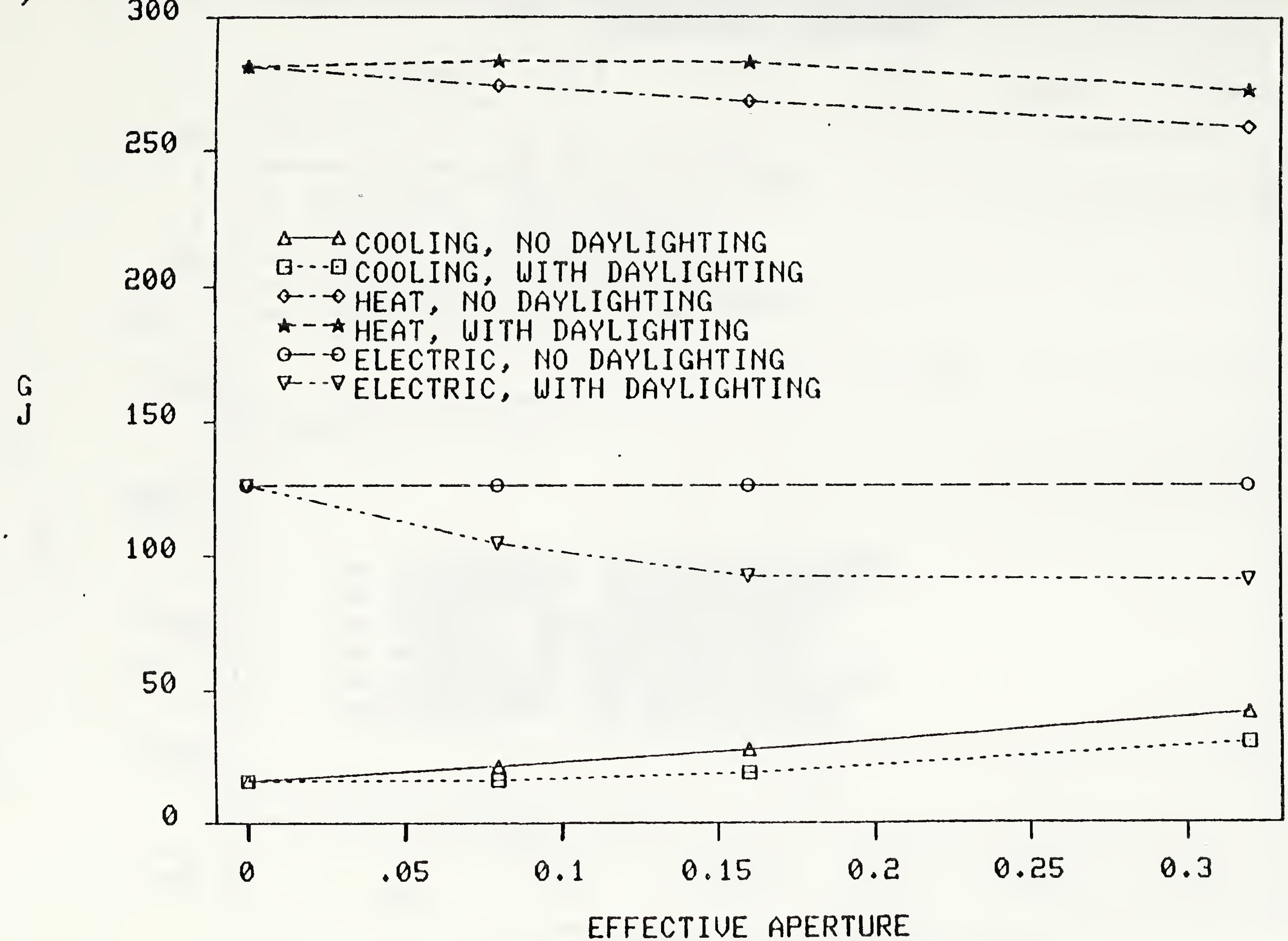


Figure 267. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
NORTH WINDOW, BRICK FREESTANDING

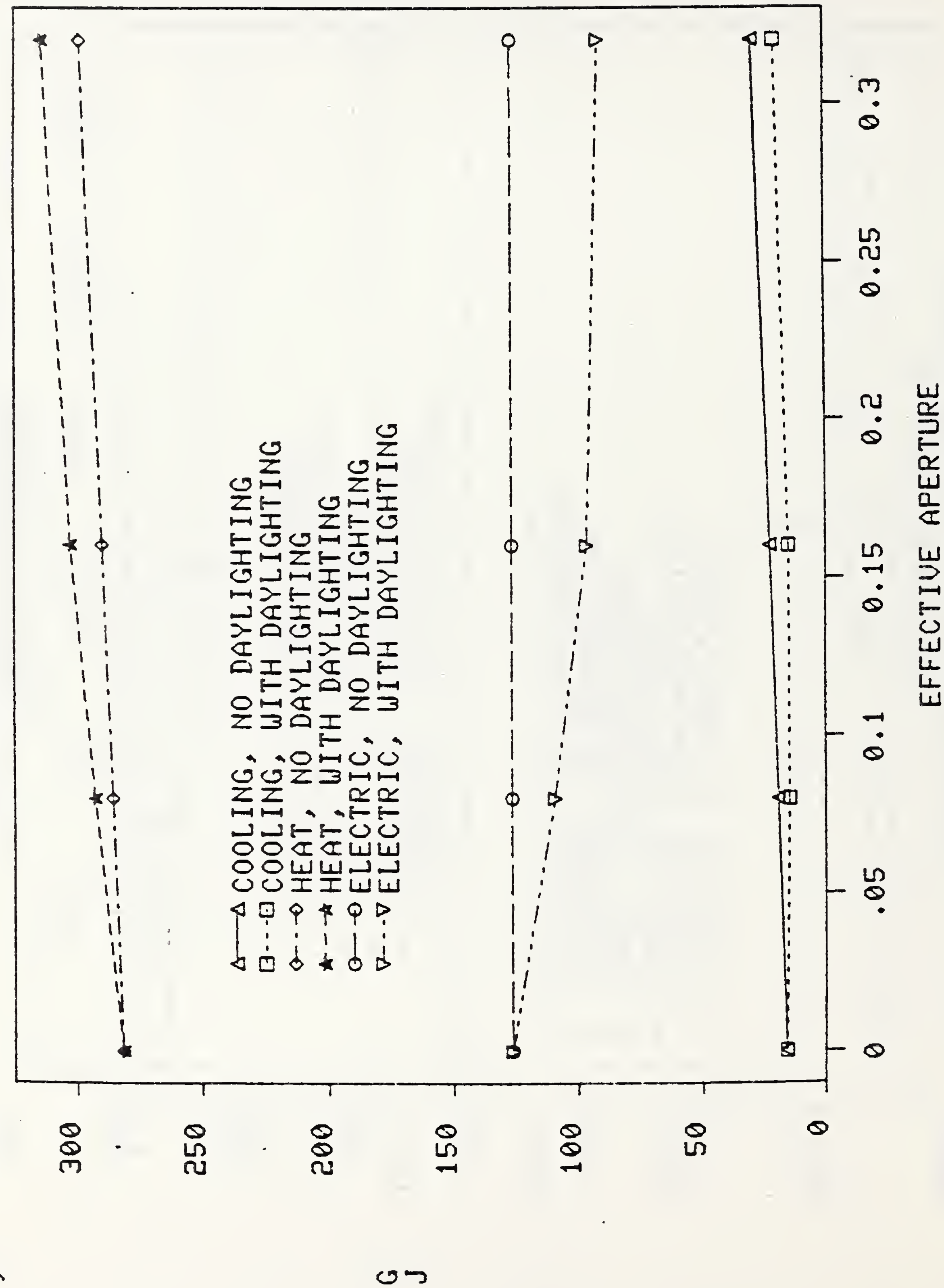


Figure 268. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
SKYLIGHTS, BRICK ATTACHED

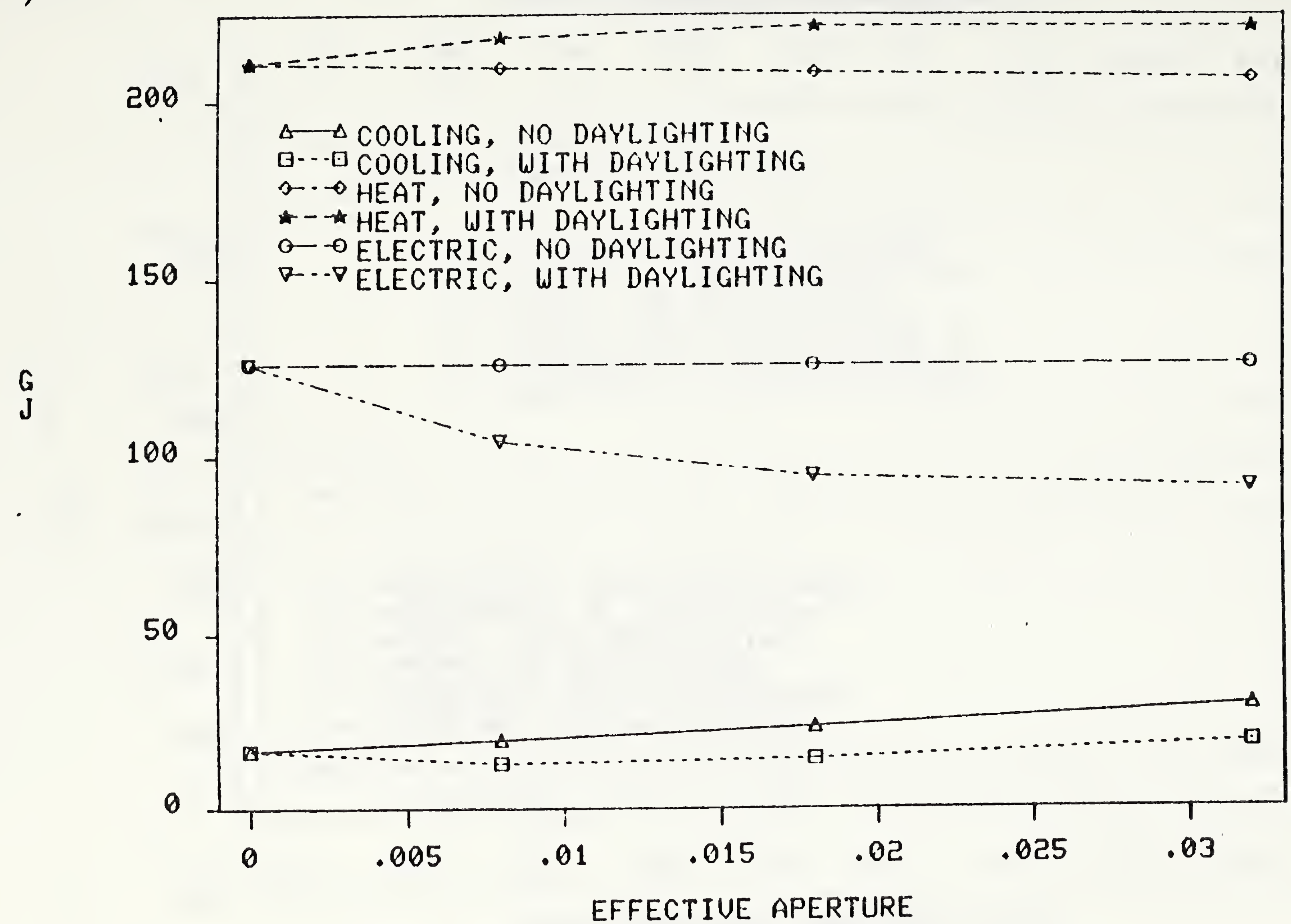


Figure 269. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston) SOUTH SAWTOOTH, BRICK ATTACHED

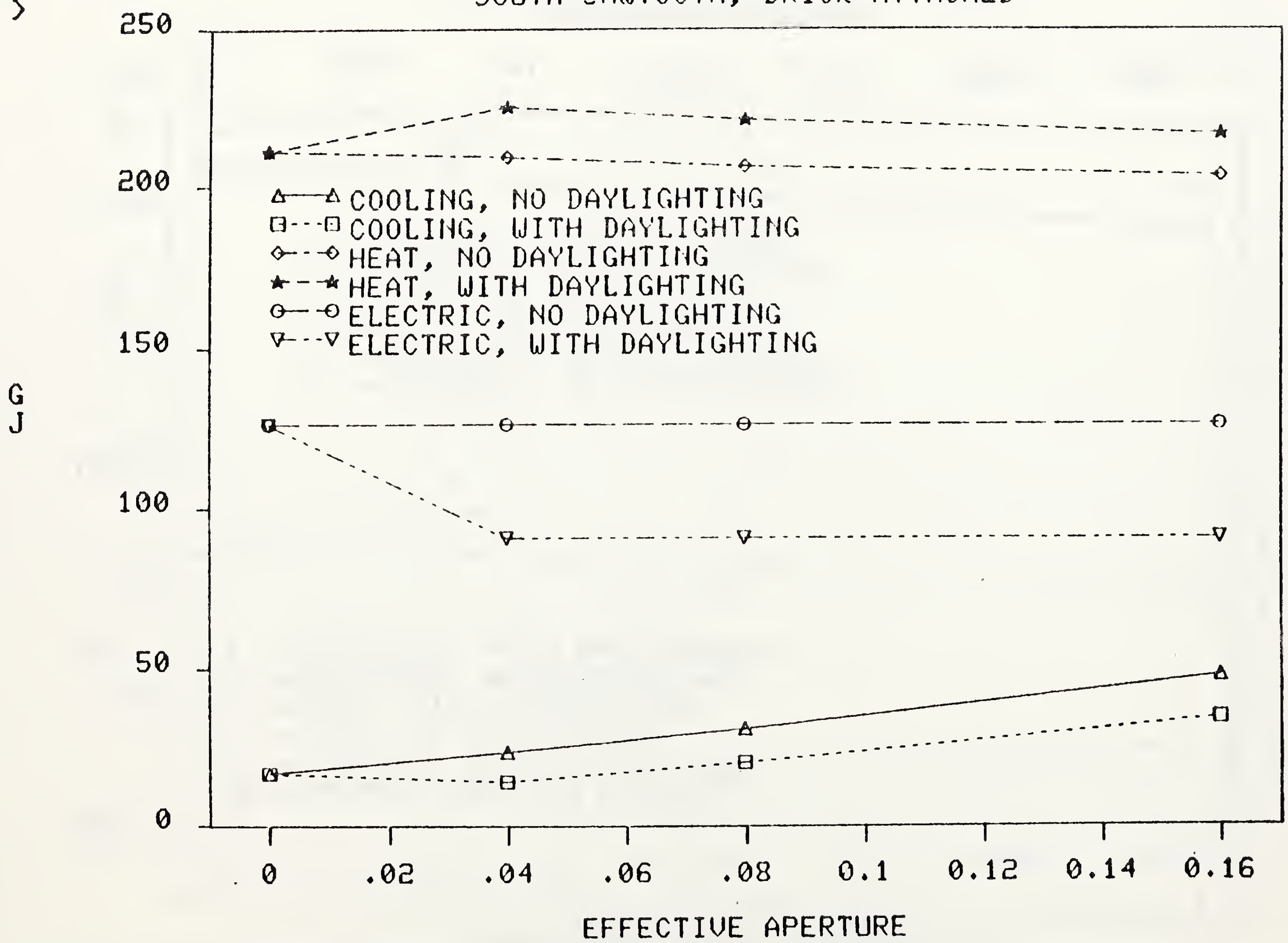


Figure 270. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
NORTH SAWTOOTH, BRICK ATTACHED

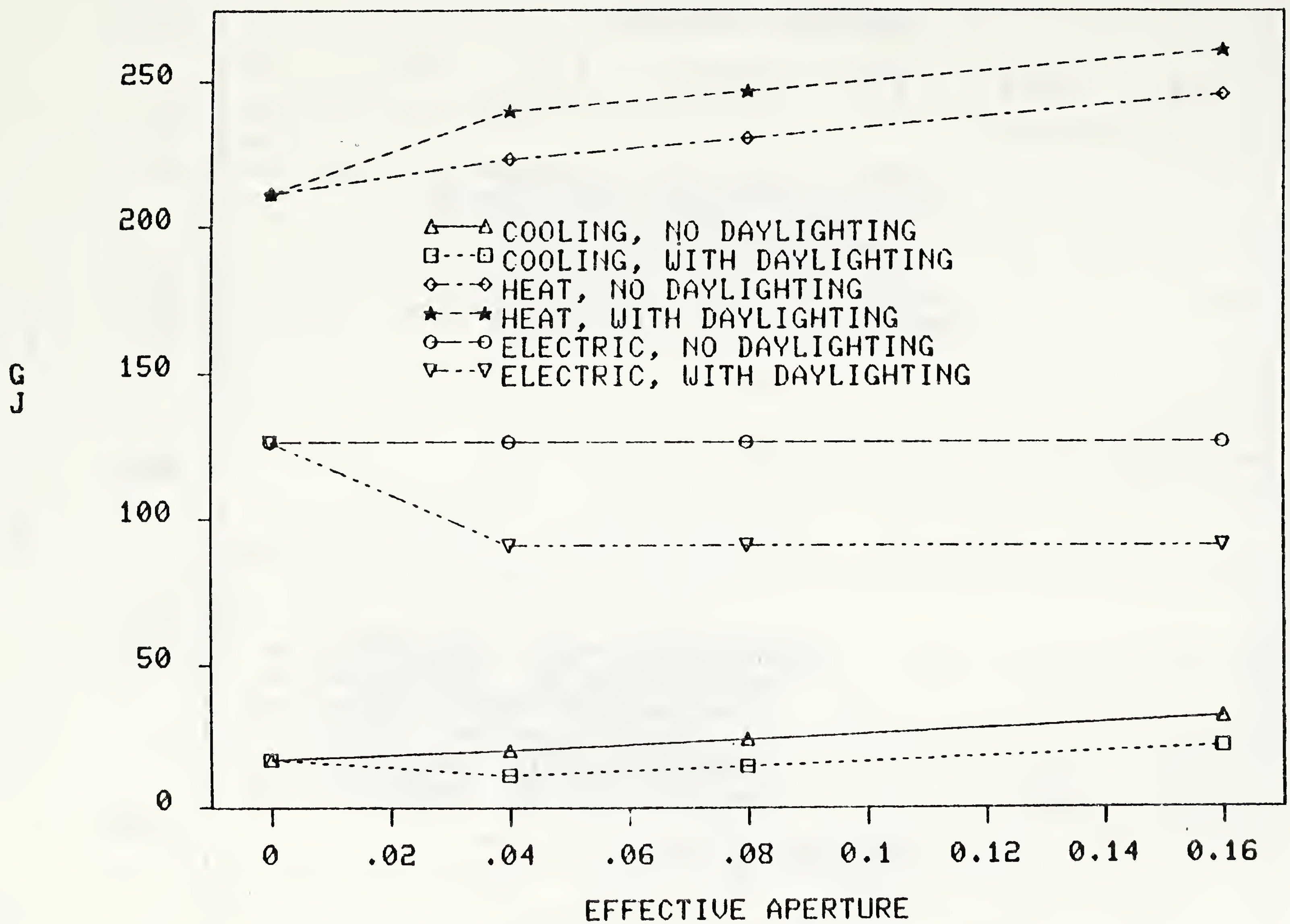


Figure 271. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston) SOUTH WINDOW, BRICK ATTACHED

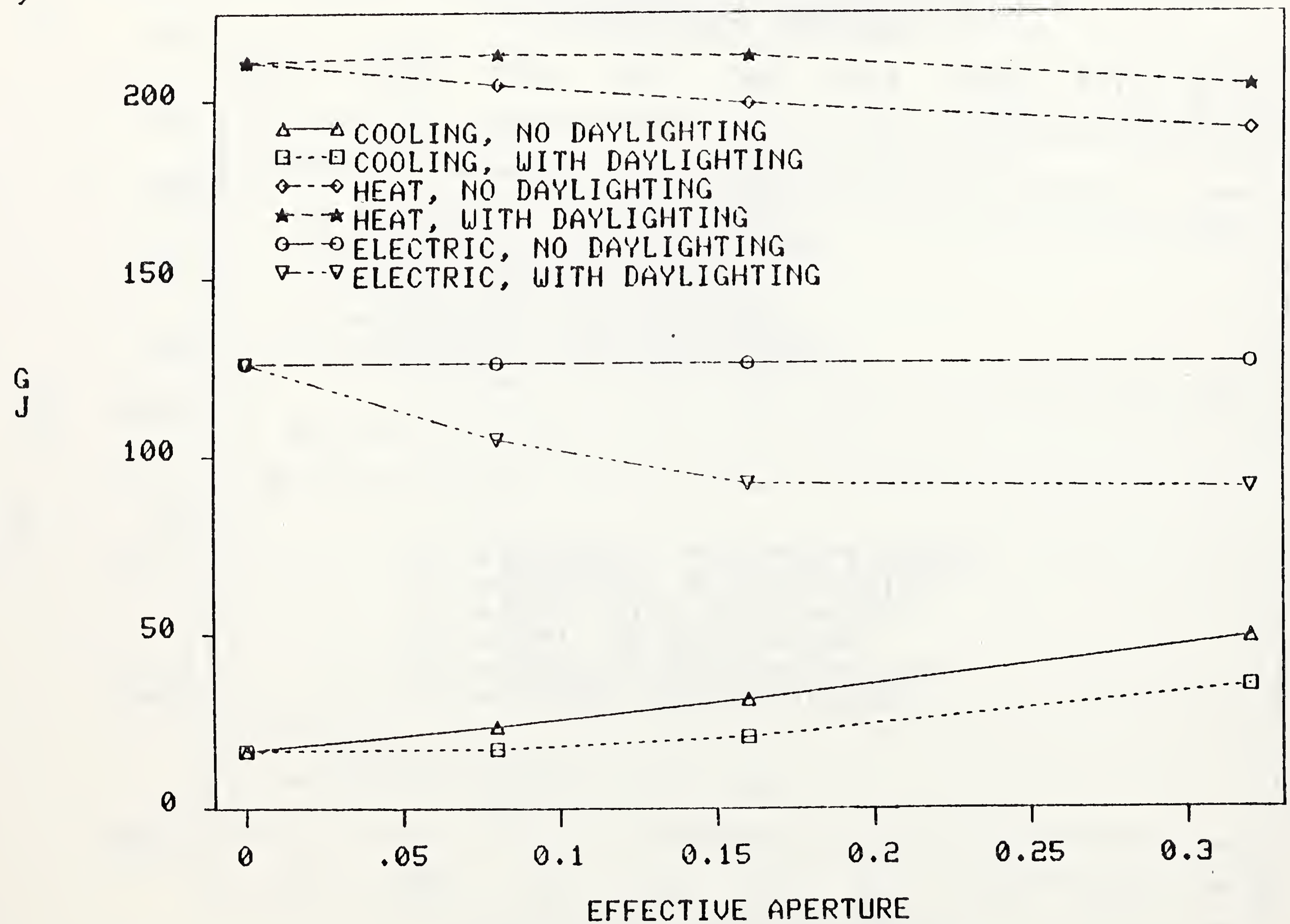


Figure 272. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
NORTH WINDOW, BRICK ATTACHED

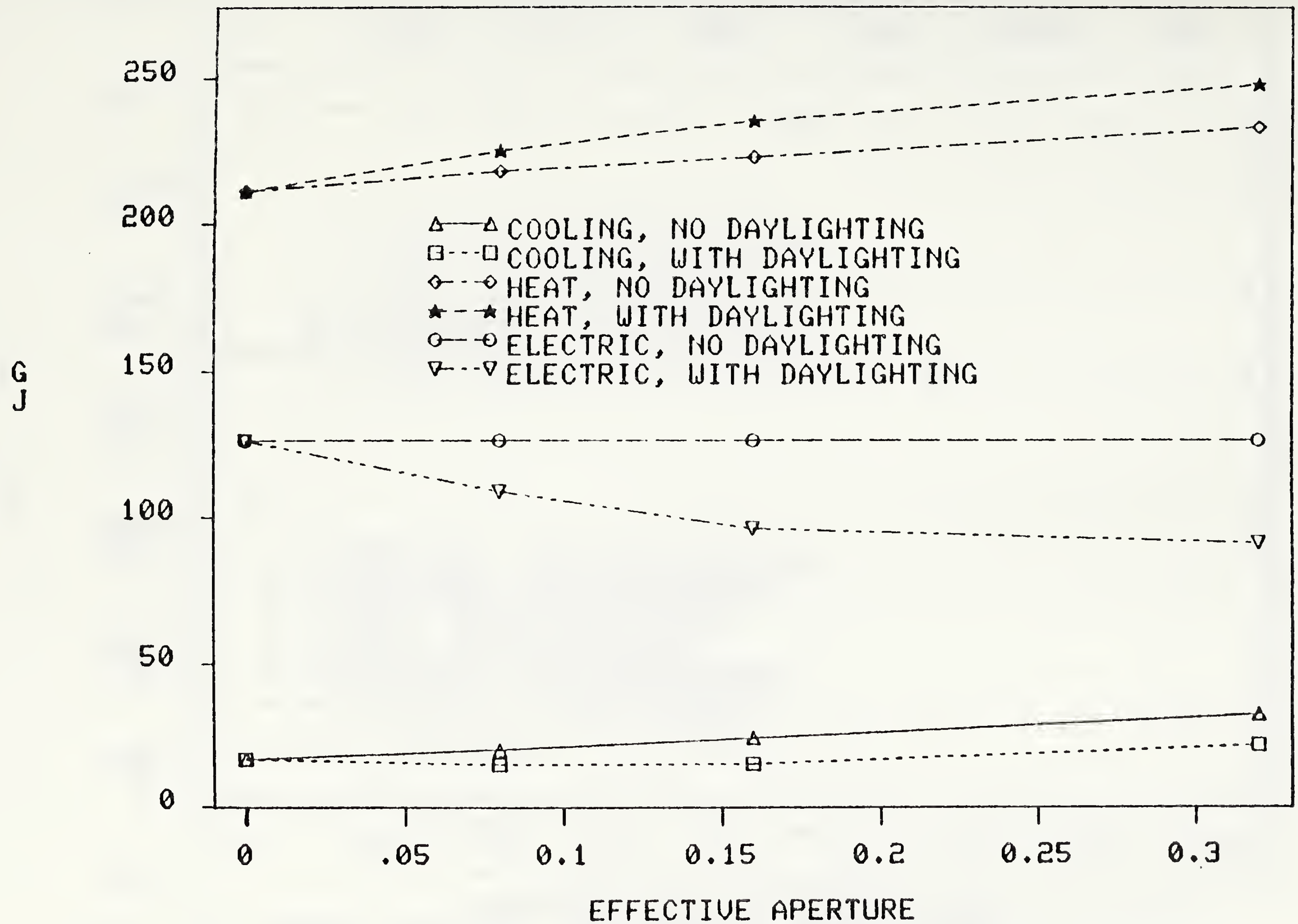


Figure 273. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
SKYLIGHTS, METAL FREESTANDING

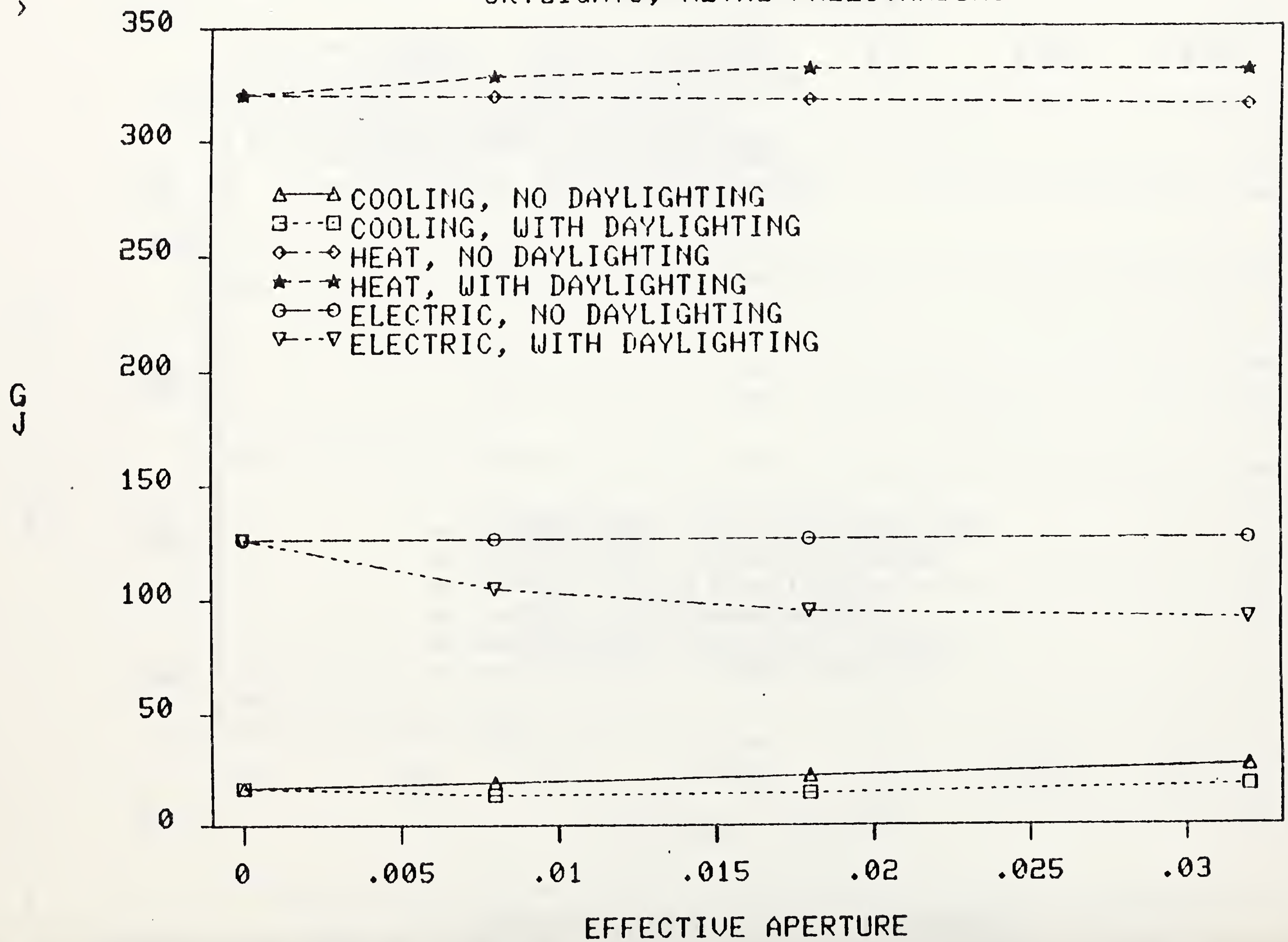


Figure 274. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
SOUTH SAWTOOTH, METAL FREESTANDING

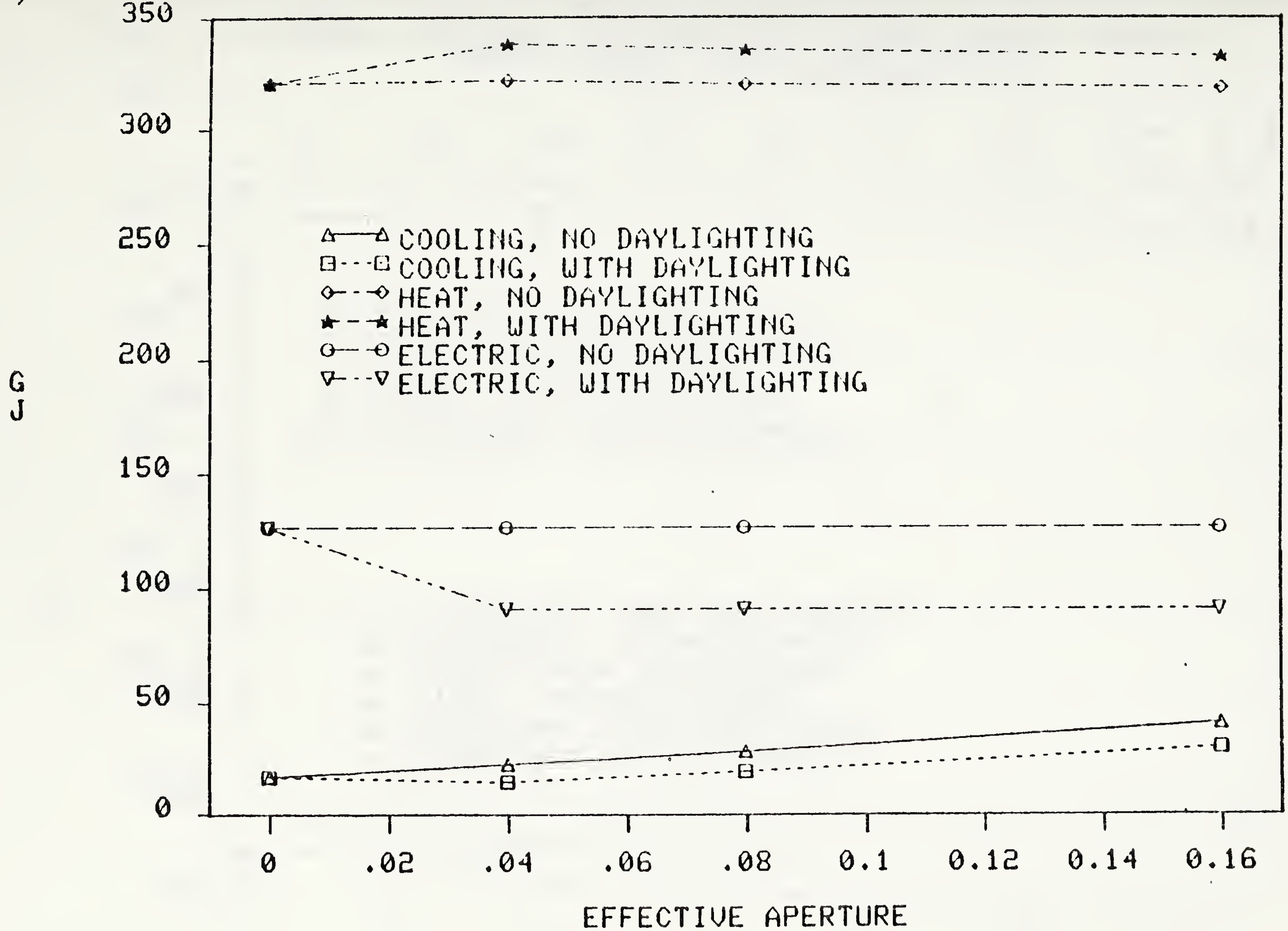


Figure 275. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
NORTH SAWTOOTH, METAL FREESTANDING

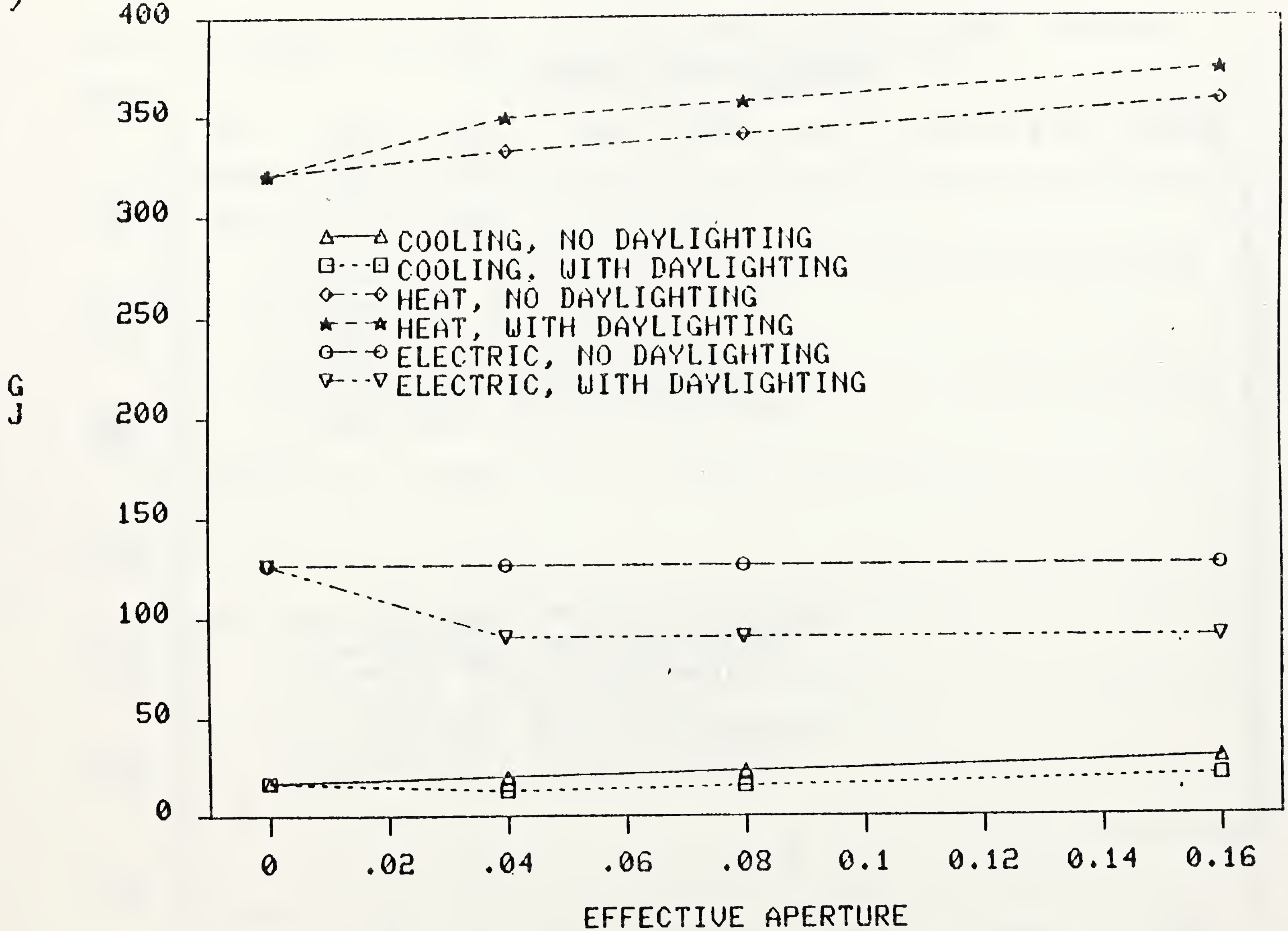


Figure 276. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
SOUTH WINDOW, METAL FREESTANDING

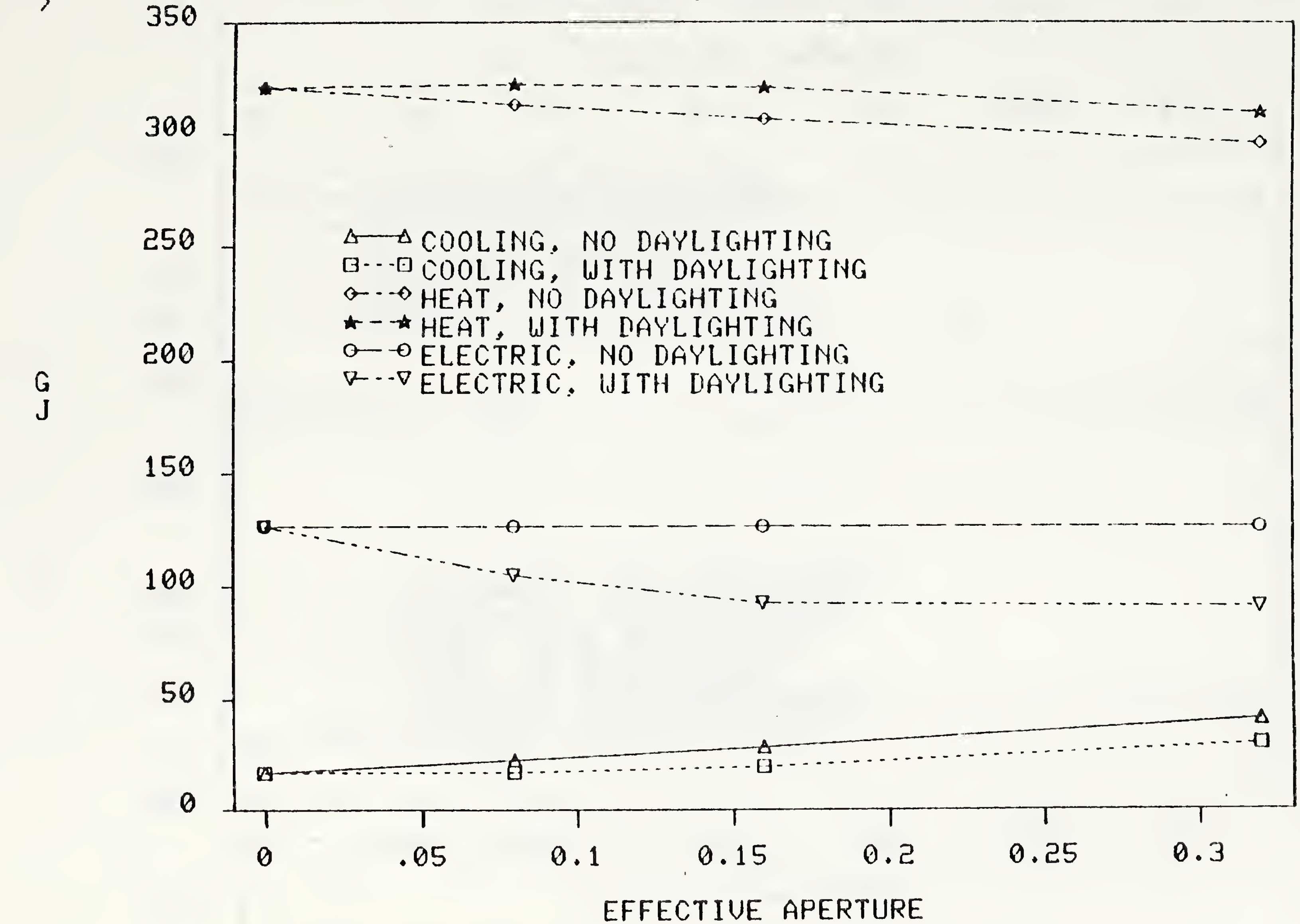


Figure 277. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
NORTH WINDOW, METAL FREESTANDING

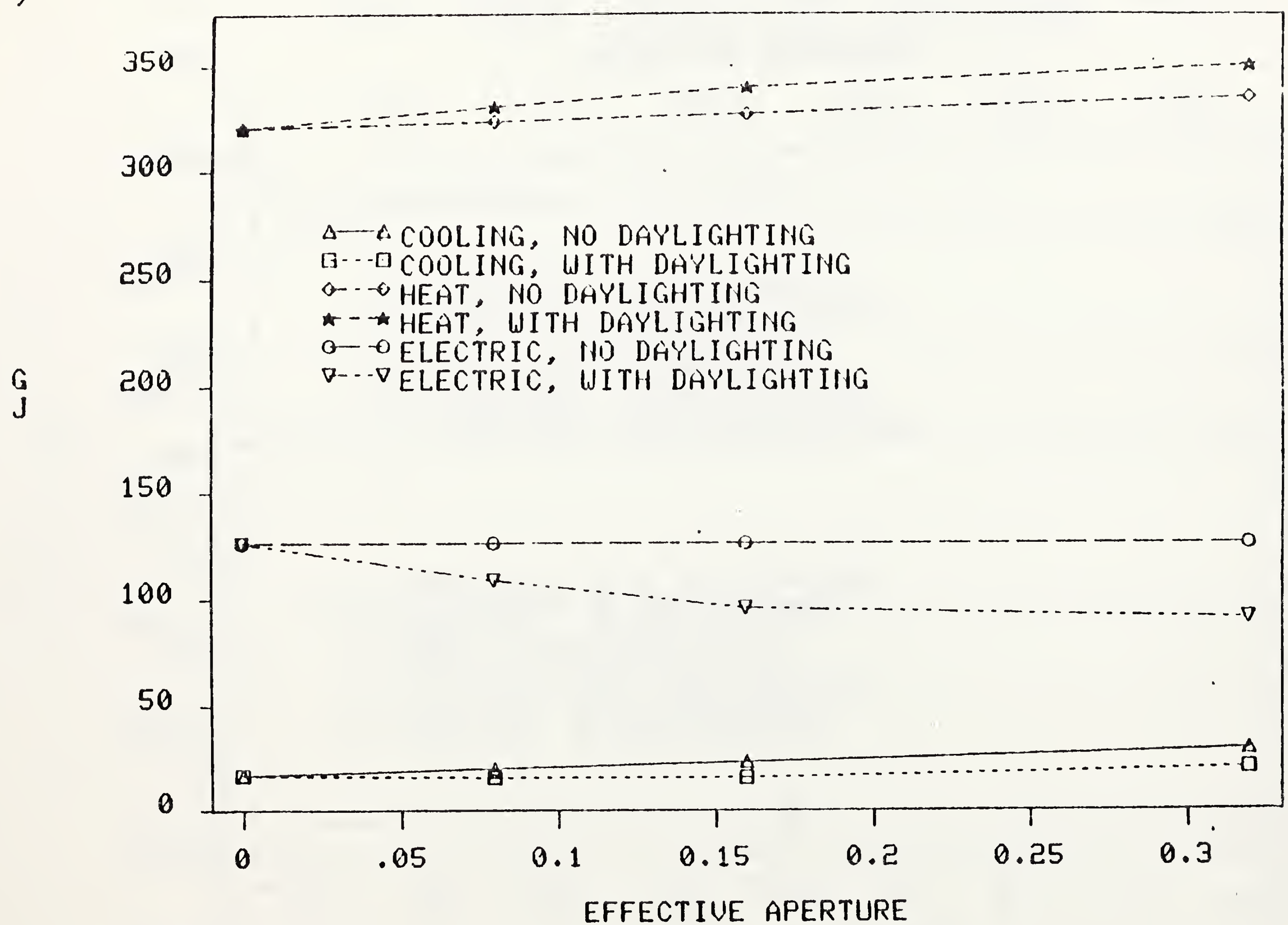


Figure 278. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston) SKYLIGHTS, METAL ATTACHED

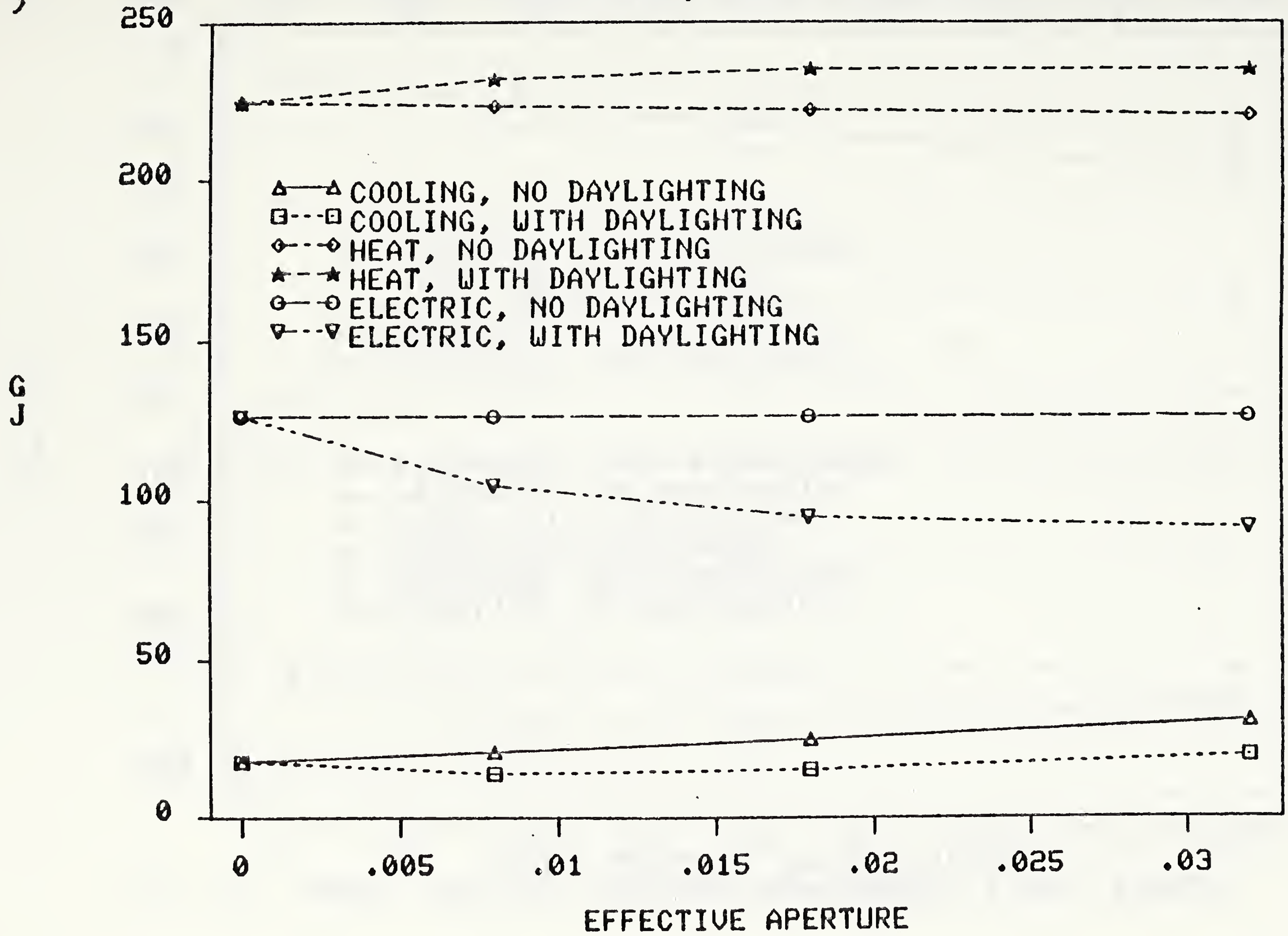


Figure 279. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
SOUTH SAWTOOTH, METAL ATTACHED

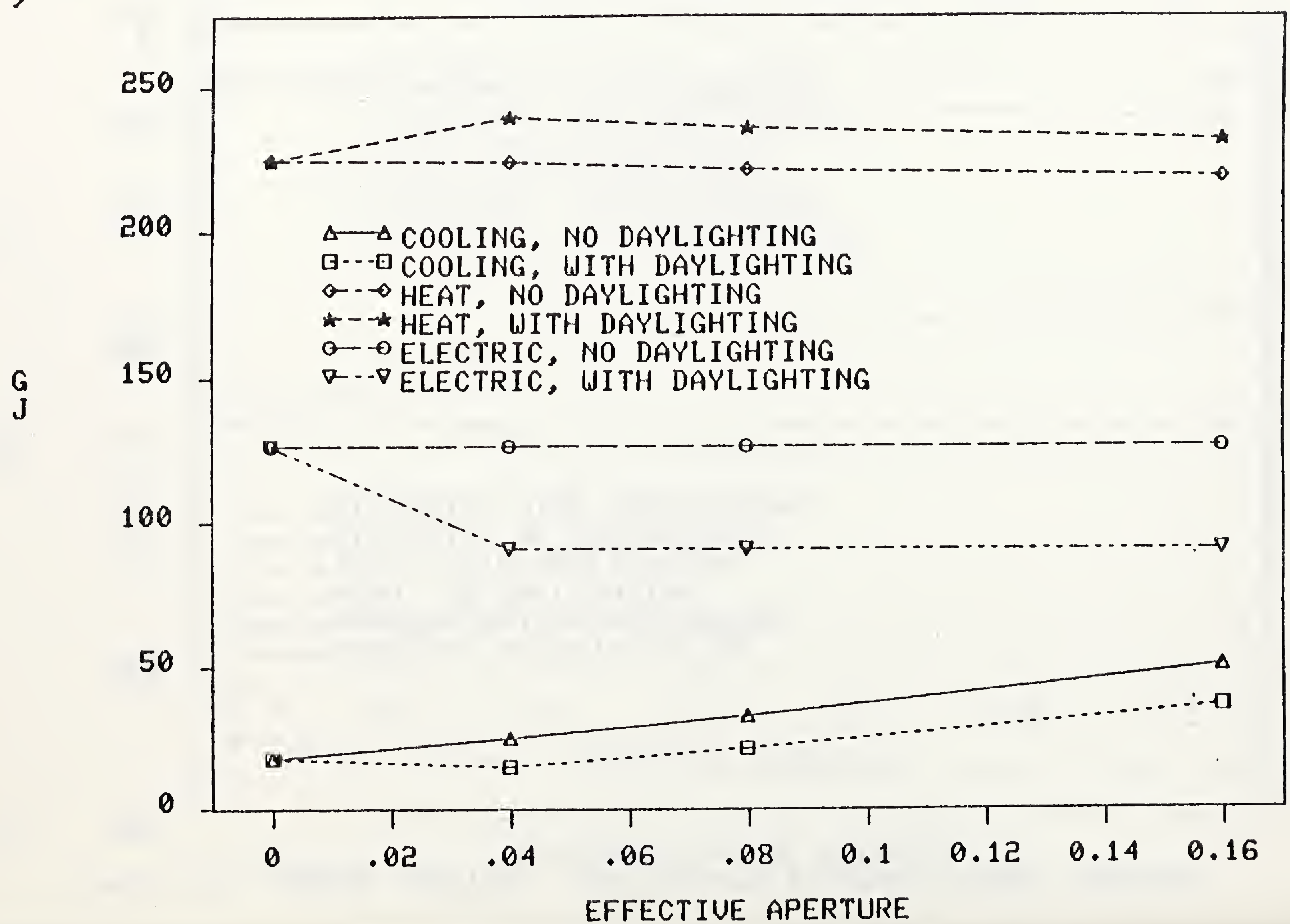


Figure 280. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
NORTH SAWTOOTH, METAL ATTACHED

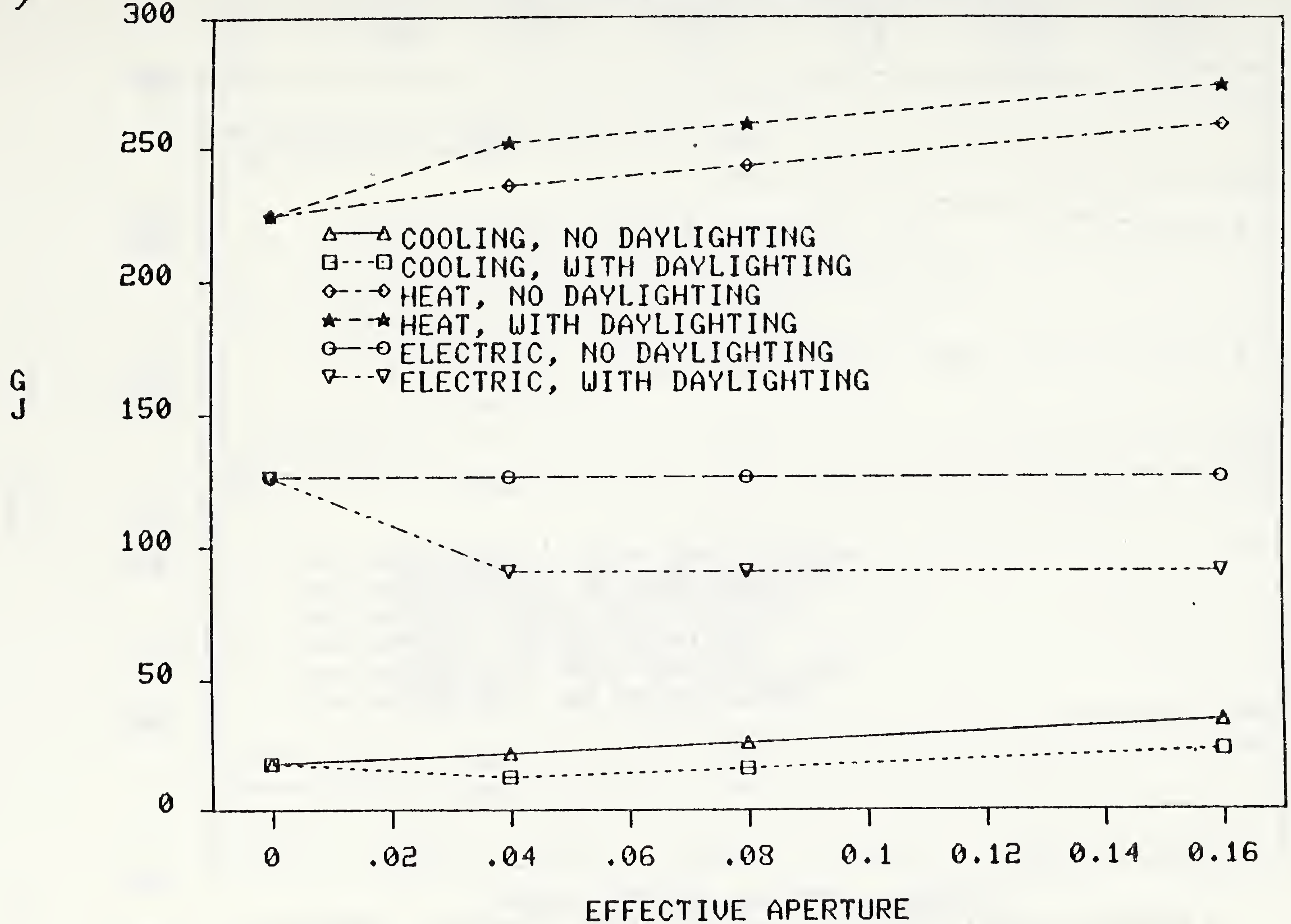


Figure 281. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
SOUTH WINDOW, METAL ATTACHED

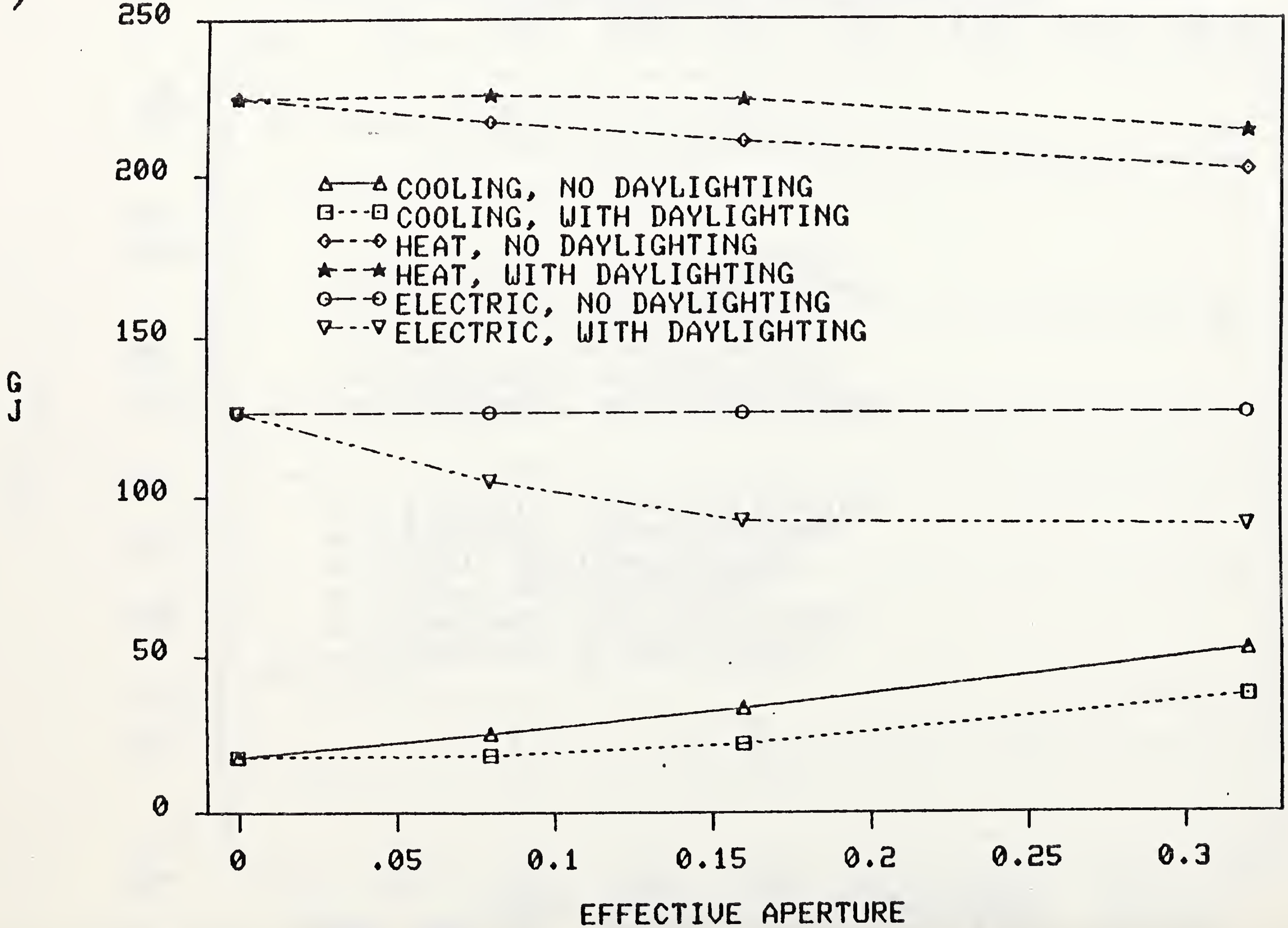


Figure 282. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Boston)
NORTH WINDOW, METAL ATTACHED

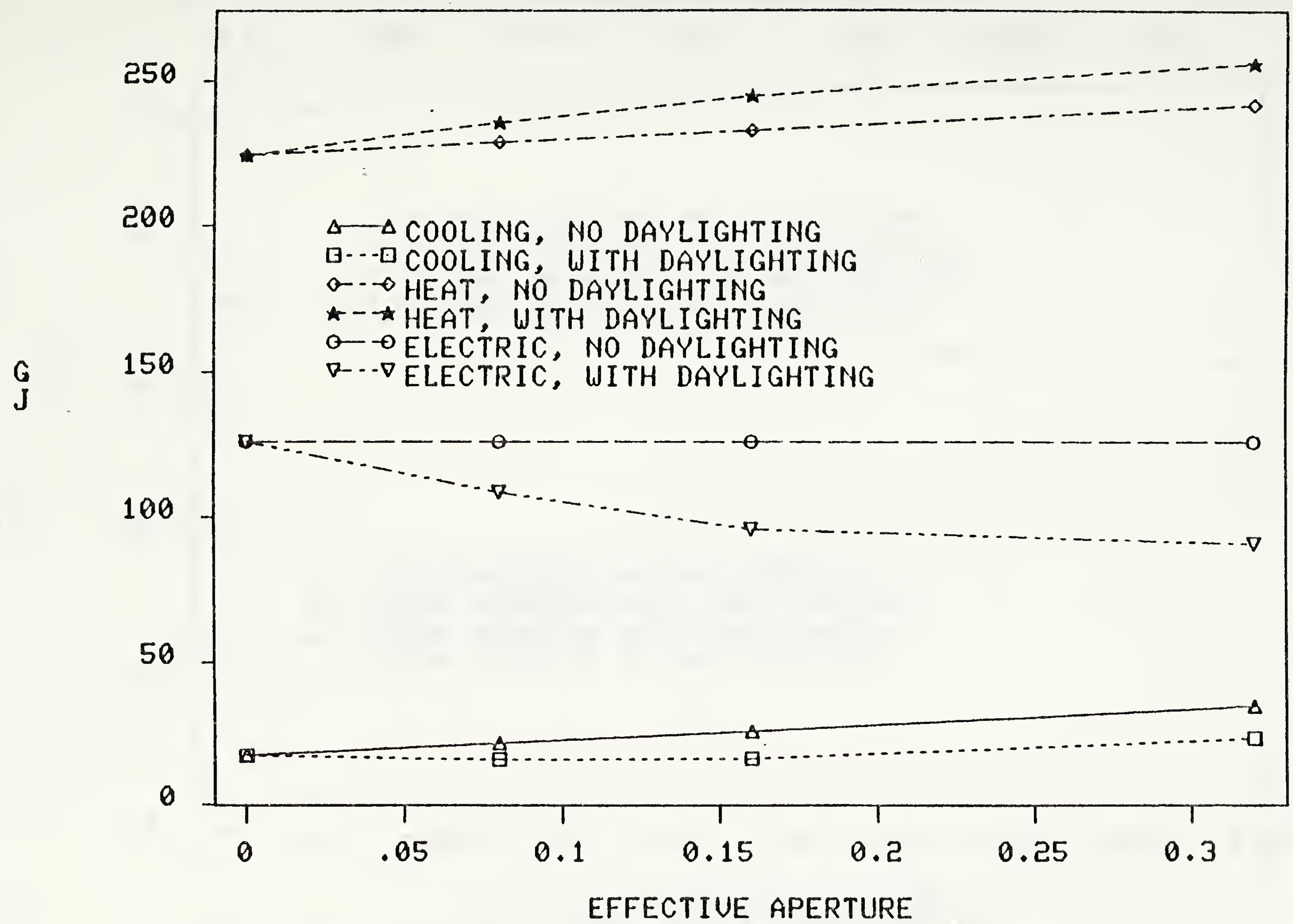


Figure 283. PEAK HEATING AND COOLING LOADS (Boston)
SKYLIGHTS, BRICK FREESTANDING

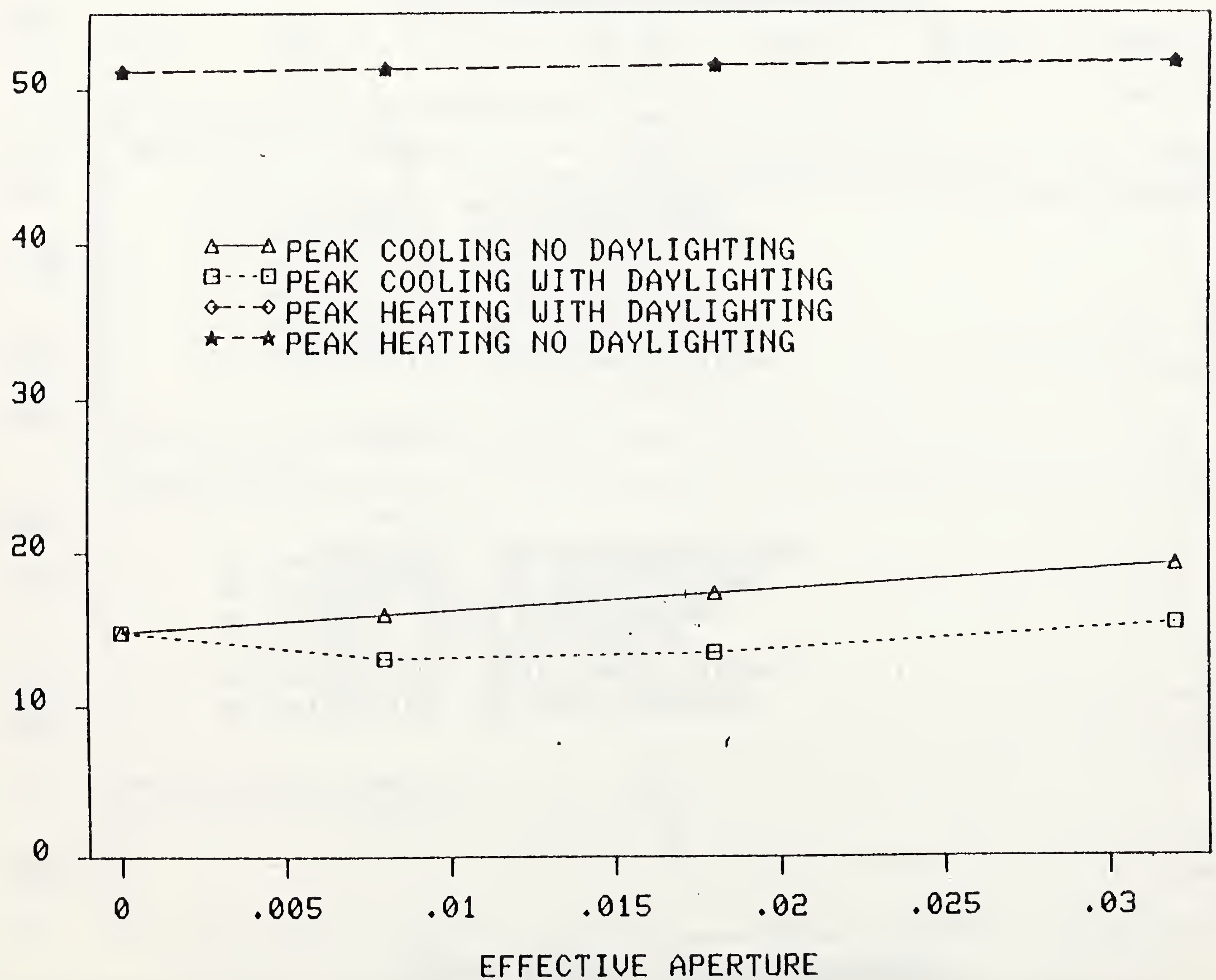


Figure 234. PEAK HEATING AND COOLING LOADS (Boston)
SOUTH SAWTOOTH, BRICK FREESTANDING

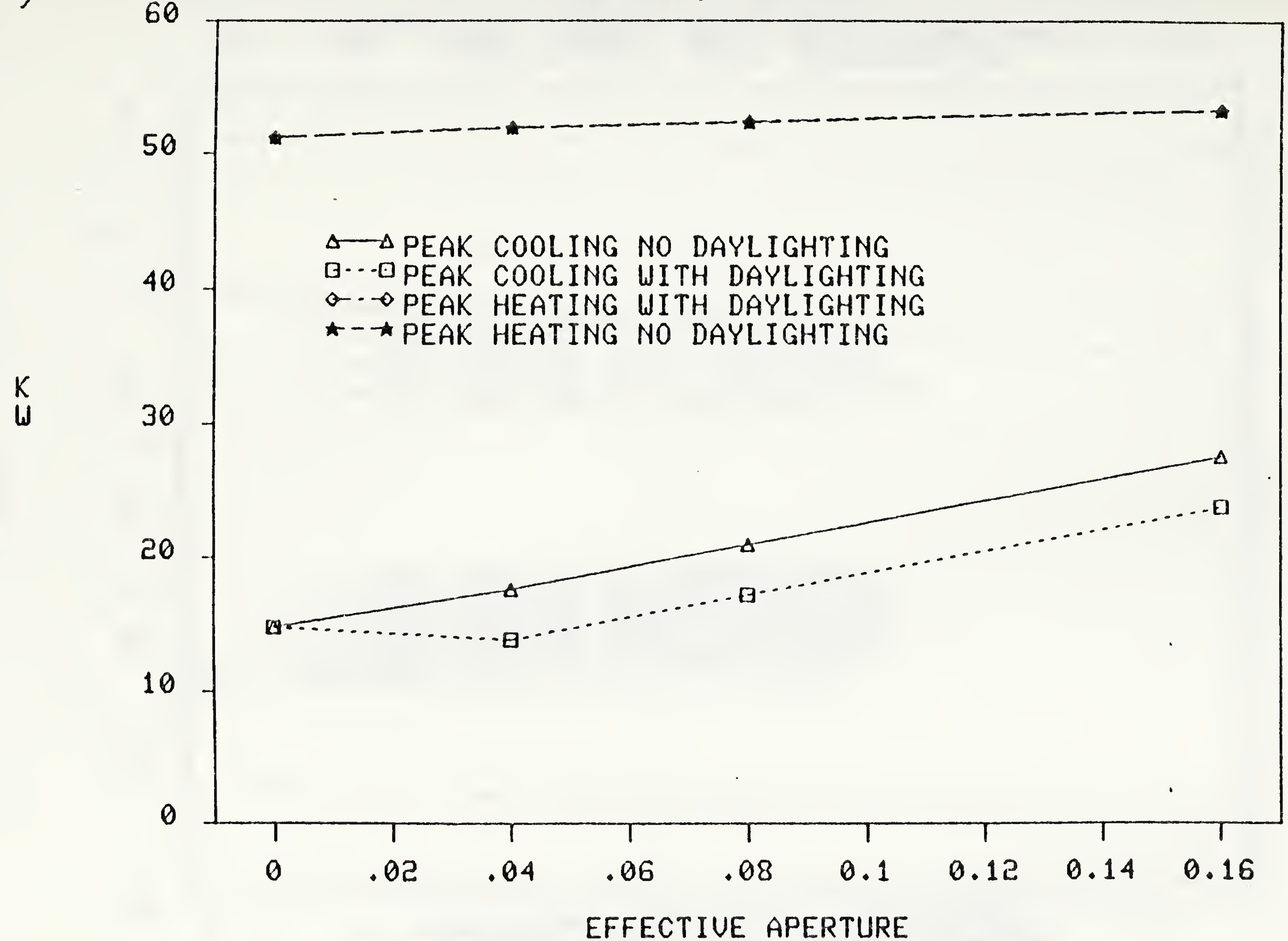


Figure 285. PEAK HEATING AND COOLING LOADS (Boston)
NORTH SAWTOOTH, BRICK FREESTANDING

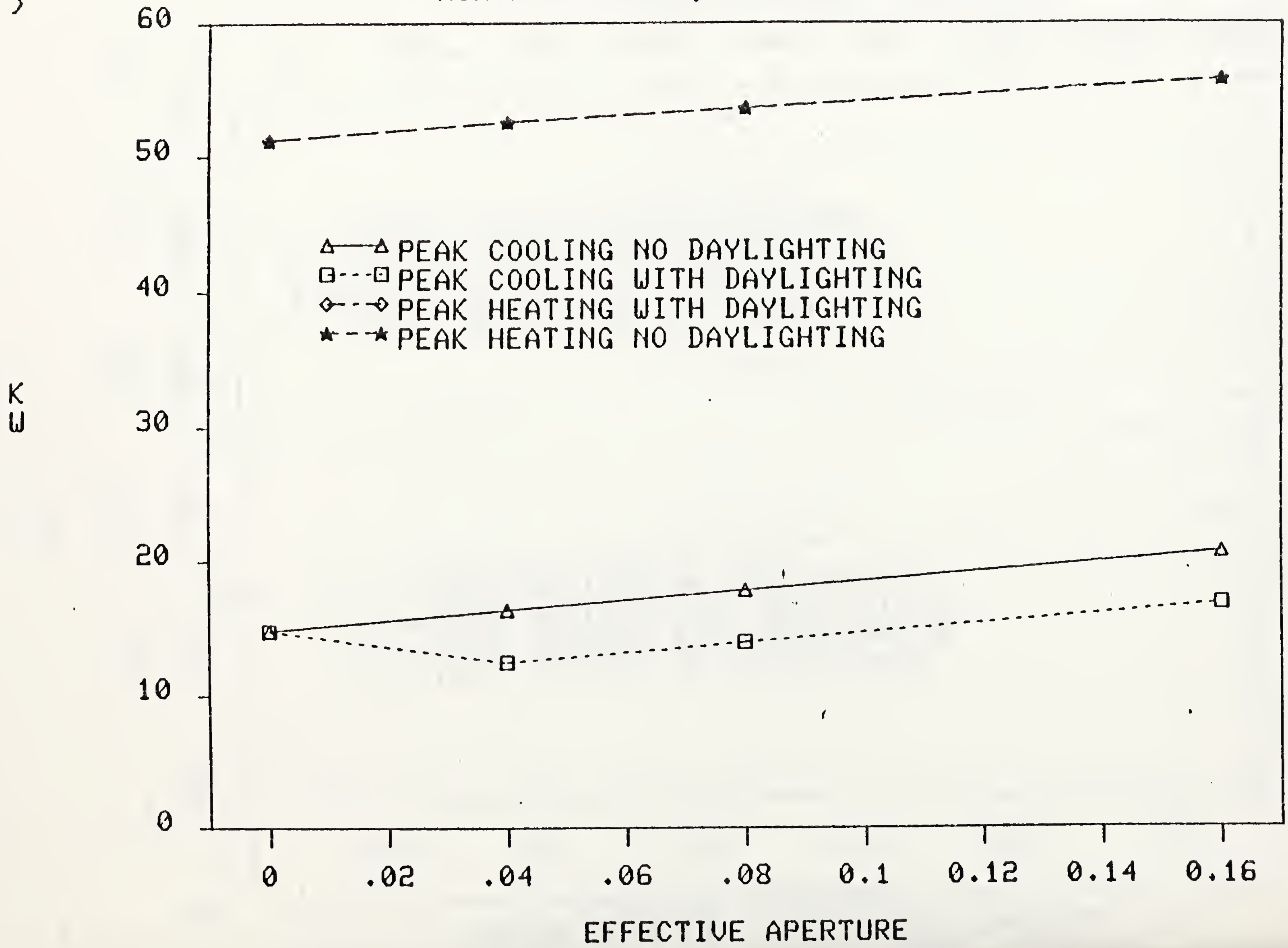


Figure 286. PEAK HEATING AND COOLING LOADS (Boston)
SOUTH WINDOW, BRICK FREESTANDING

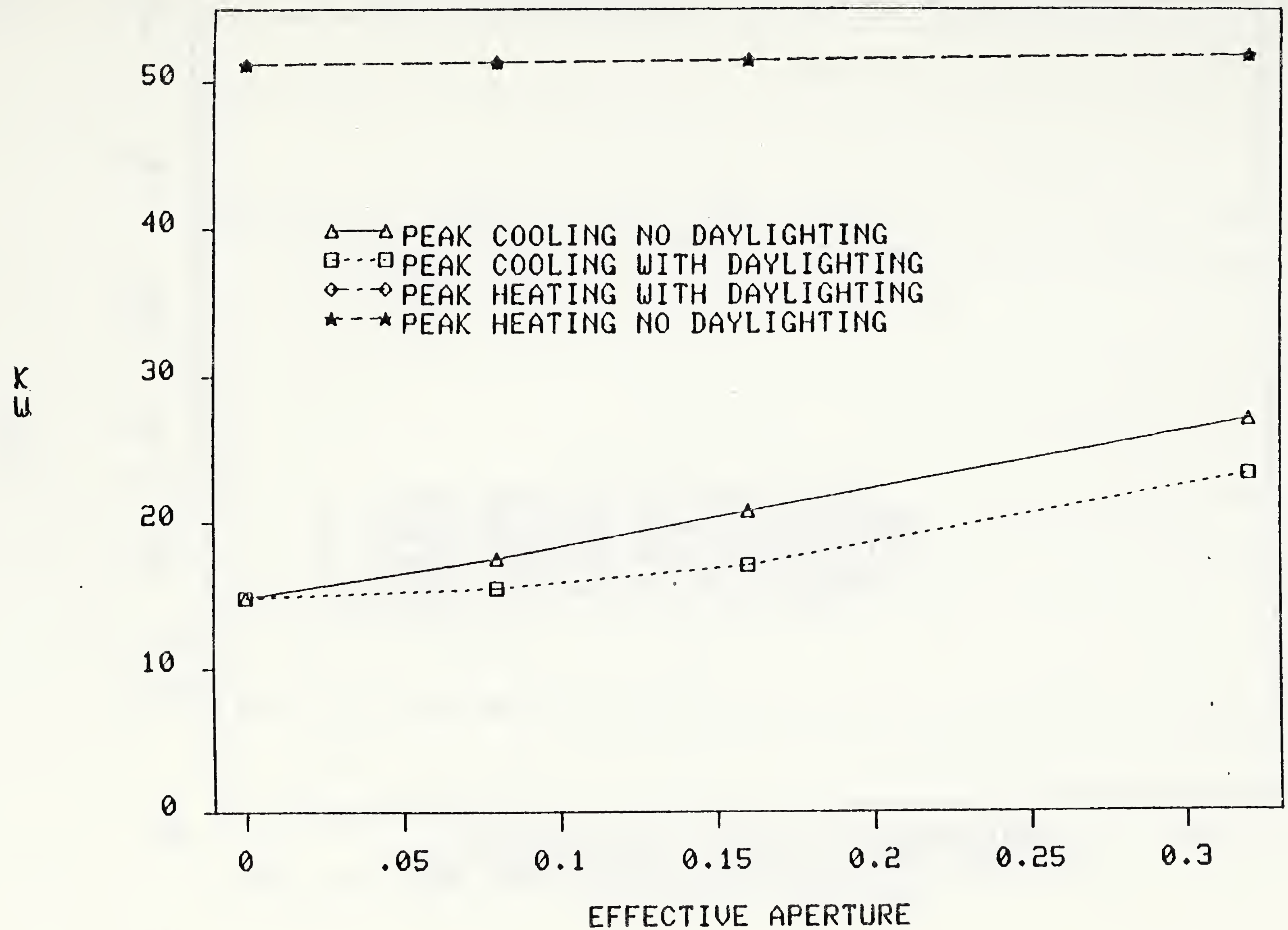


Figure 287. PEAK HEATING AND COOLING LOADS (Boston)
NORTH WINDOW, BRICK FREESTANDING

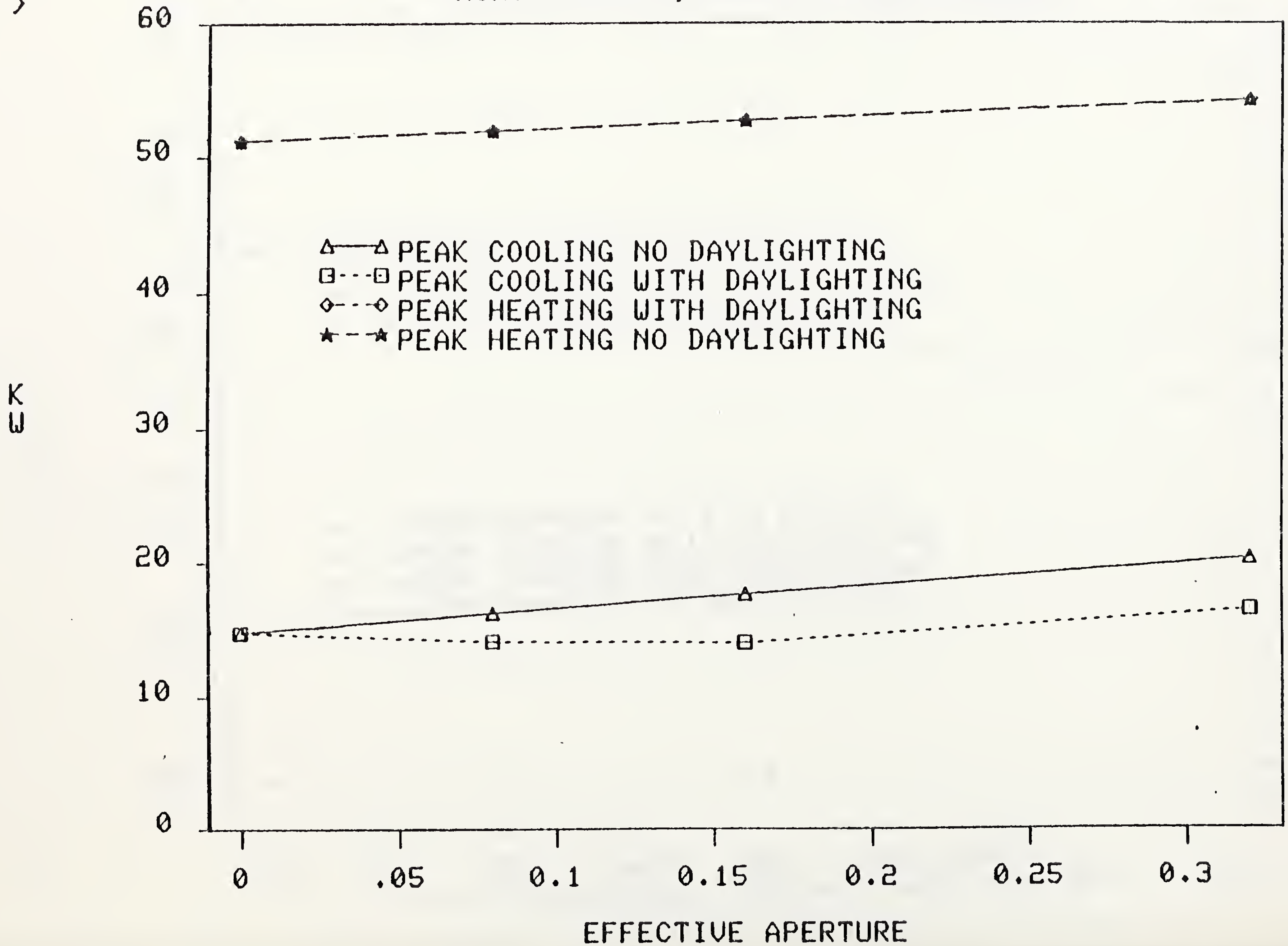


Figure 288. PEAK HEATING AND COOLING LOADS (Boston)
SKYLIGHTS, BRICK ATTACHED

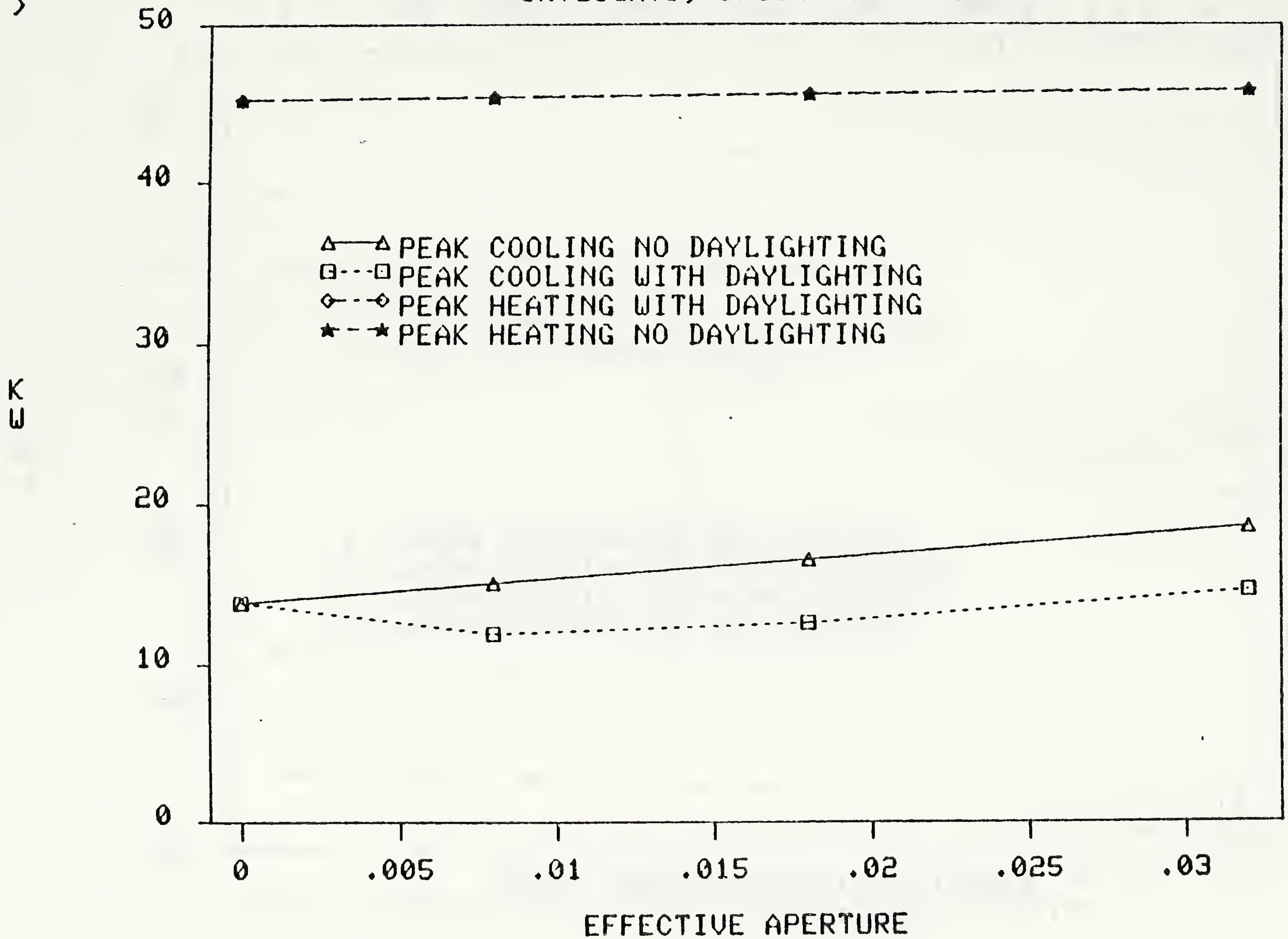


Figure 289. PEAK HEATING AND COOLING LOADS (Boston)
SOUTH SAWTOOTH, BRICK ATTACHED

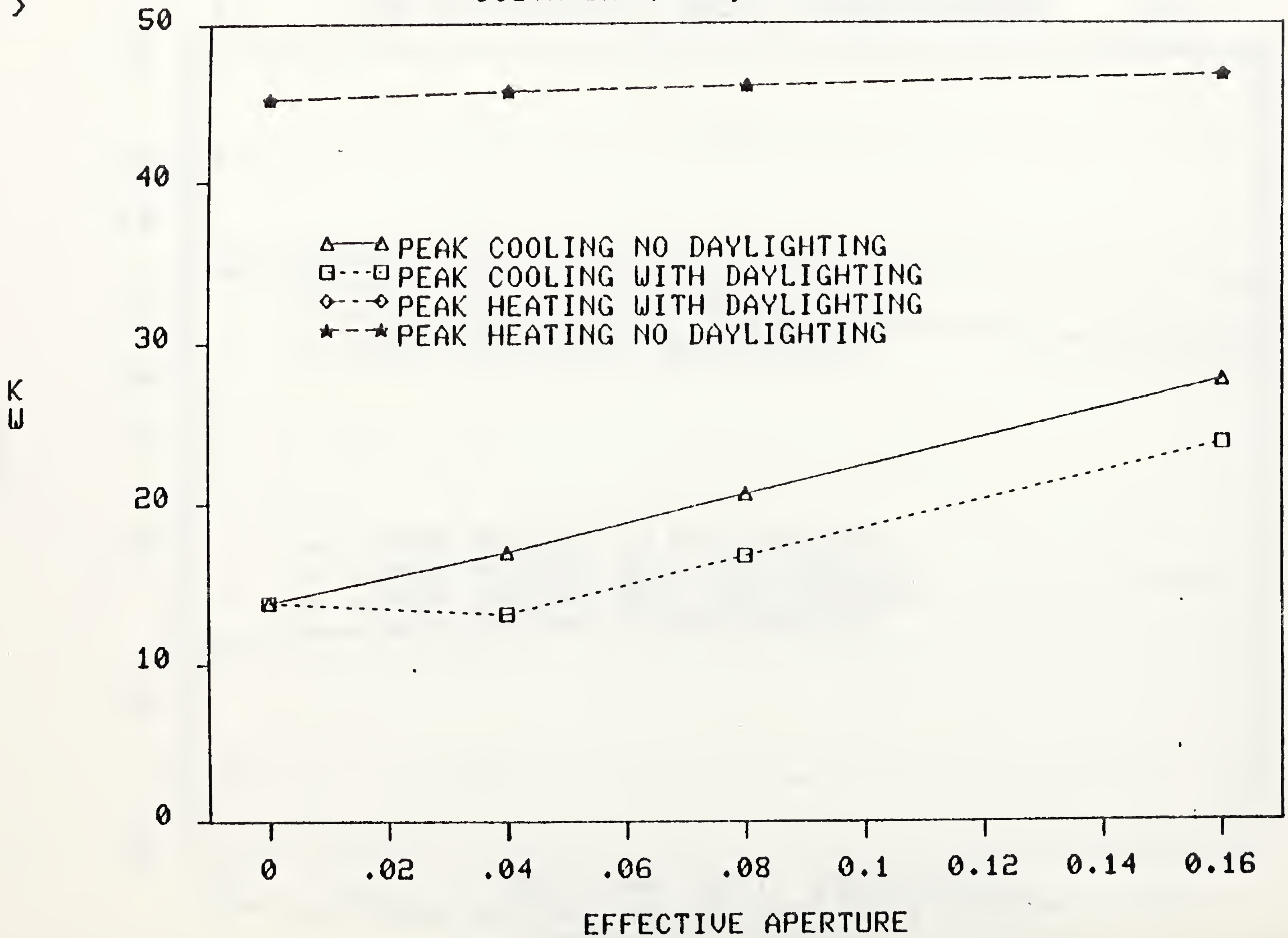


Figure 290. PEAK HEATING AND COOLING LOADS (Boston)
NORTH SAWTOOTH, BRICK ATTACHED

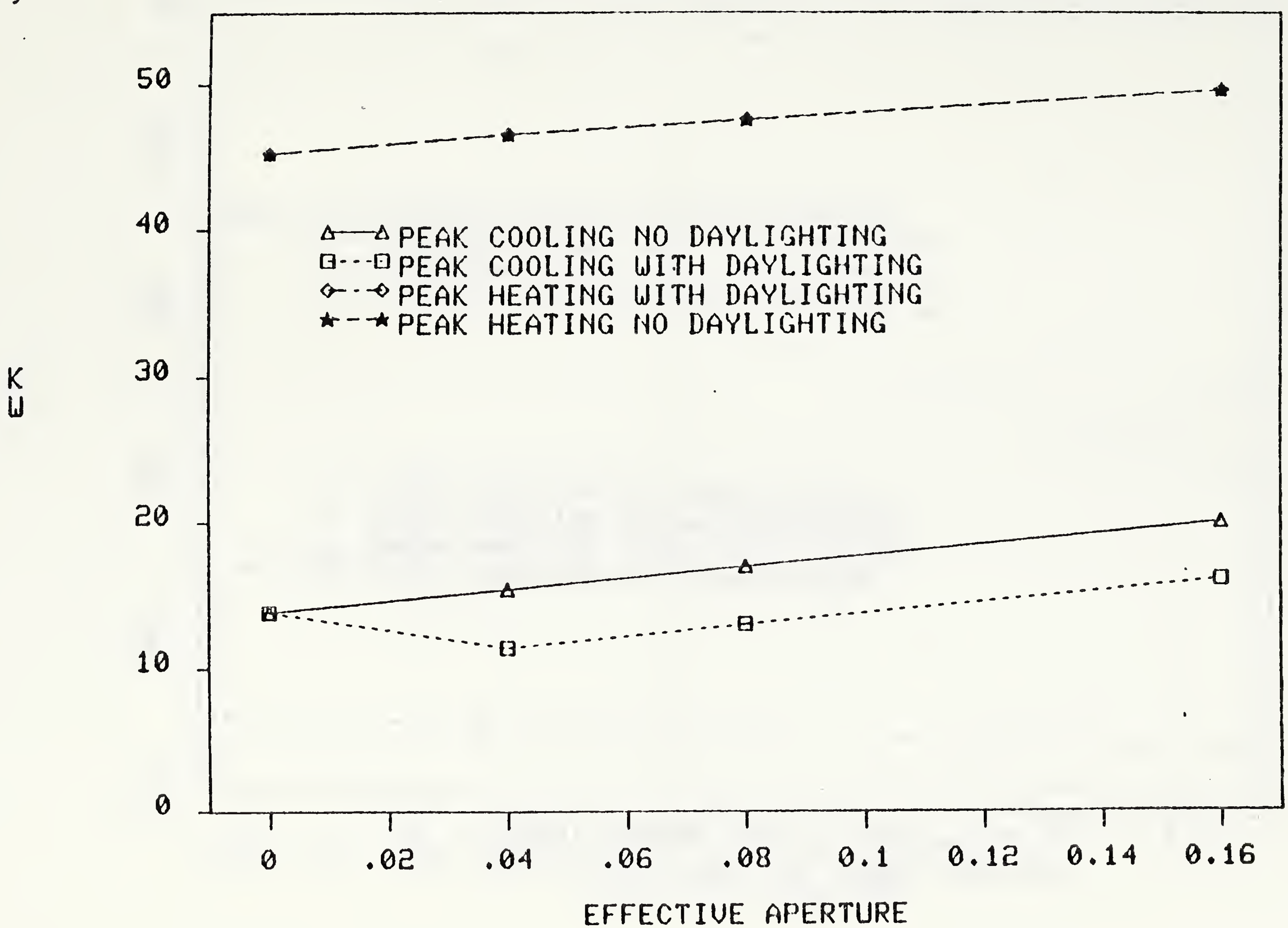


Figure 291. PEAK HEATING AND COOLING LOADS (Boston)
SOUTH WINDOW, BRICK ATTACHED

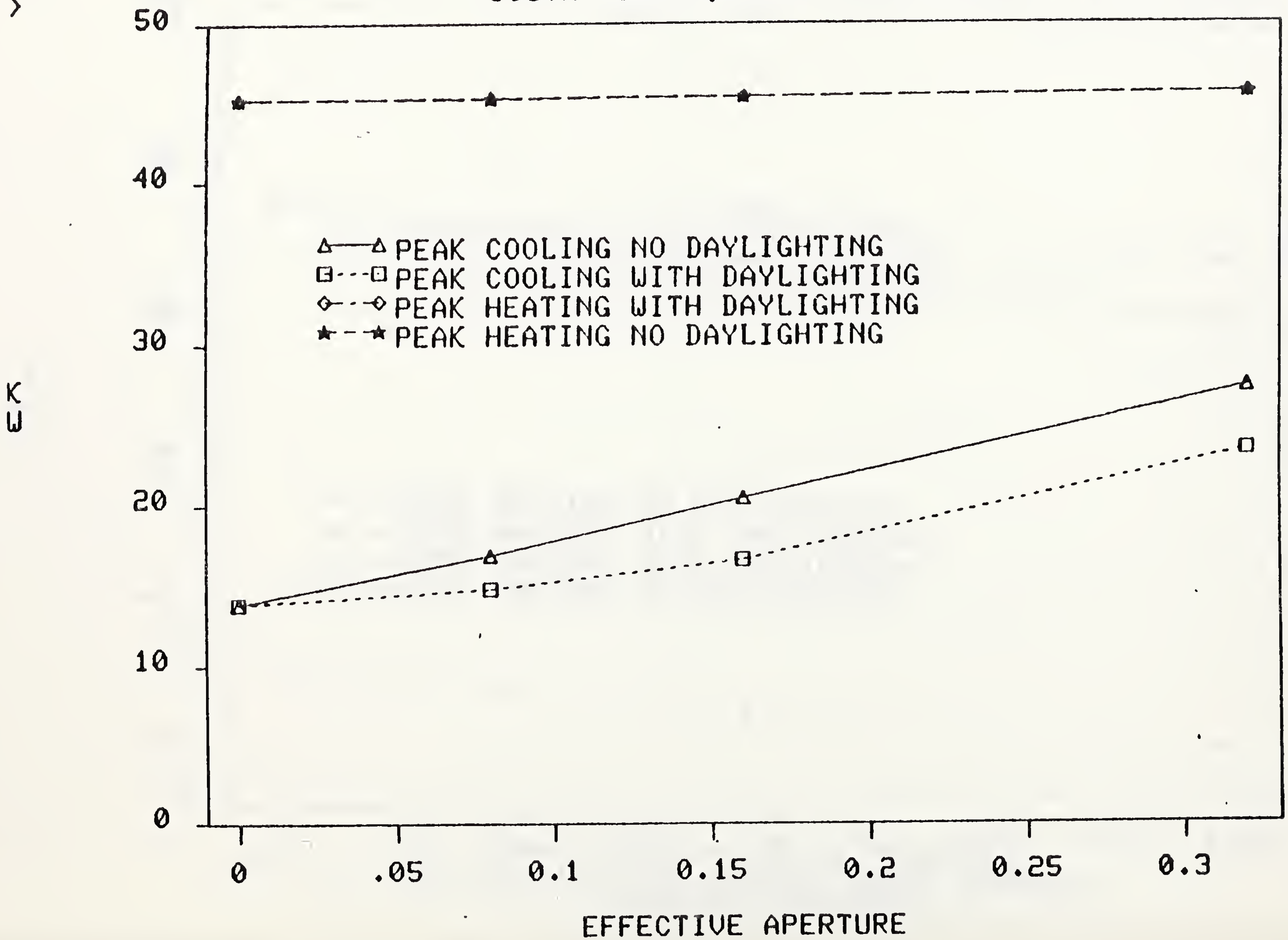


Figure 292. PEAK HEATING AND COOLING LOADS (Boston) NORTH WINDOW, BRICK ATTACHED

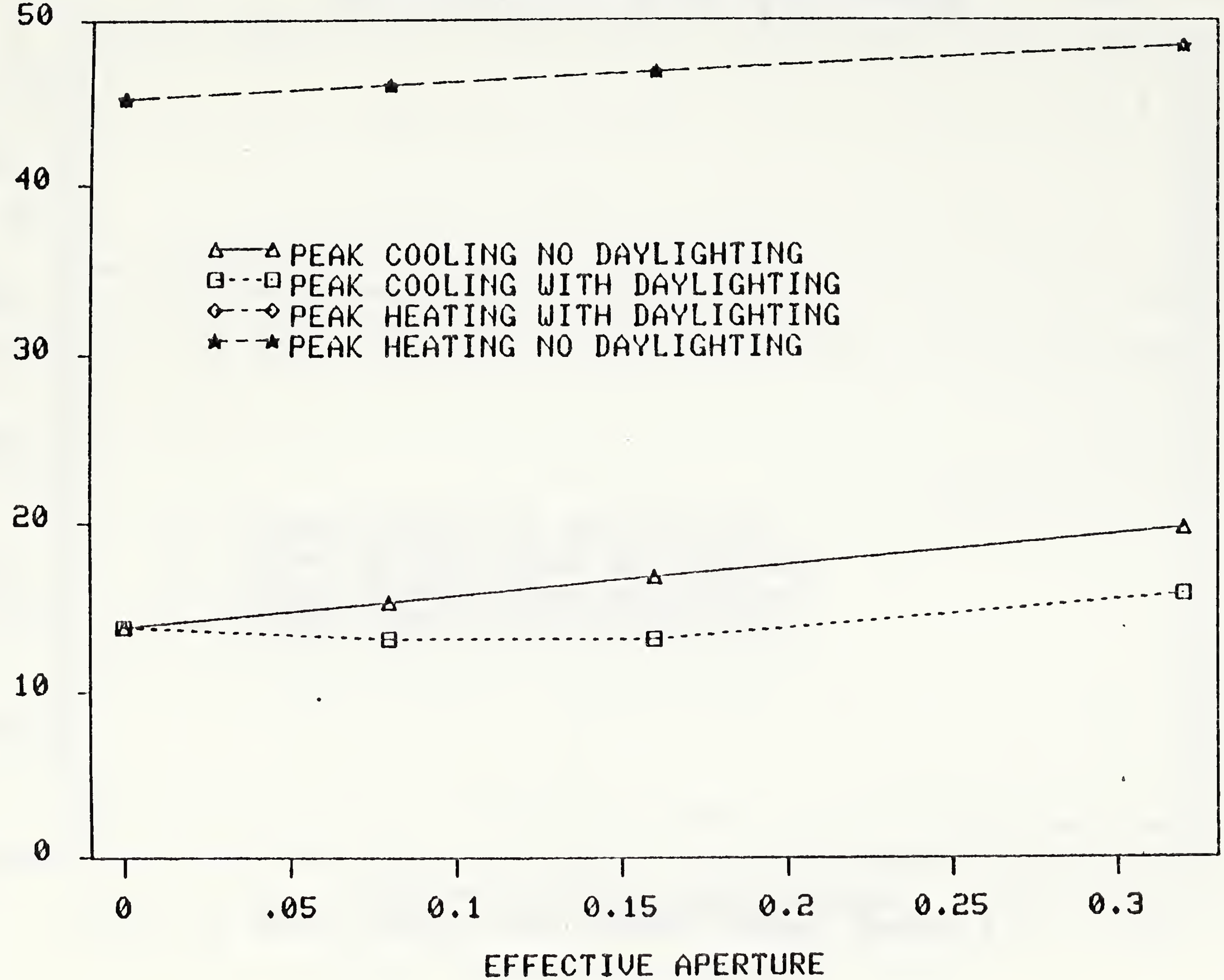


Figure 293. PEAK HEATING AND COOLING LOADS (Boston)
SKYLIGHTS, METAL FREESTANDING

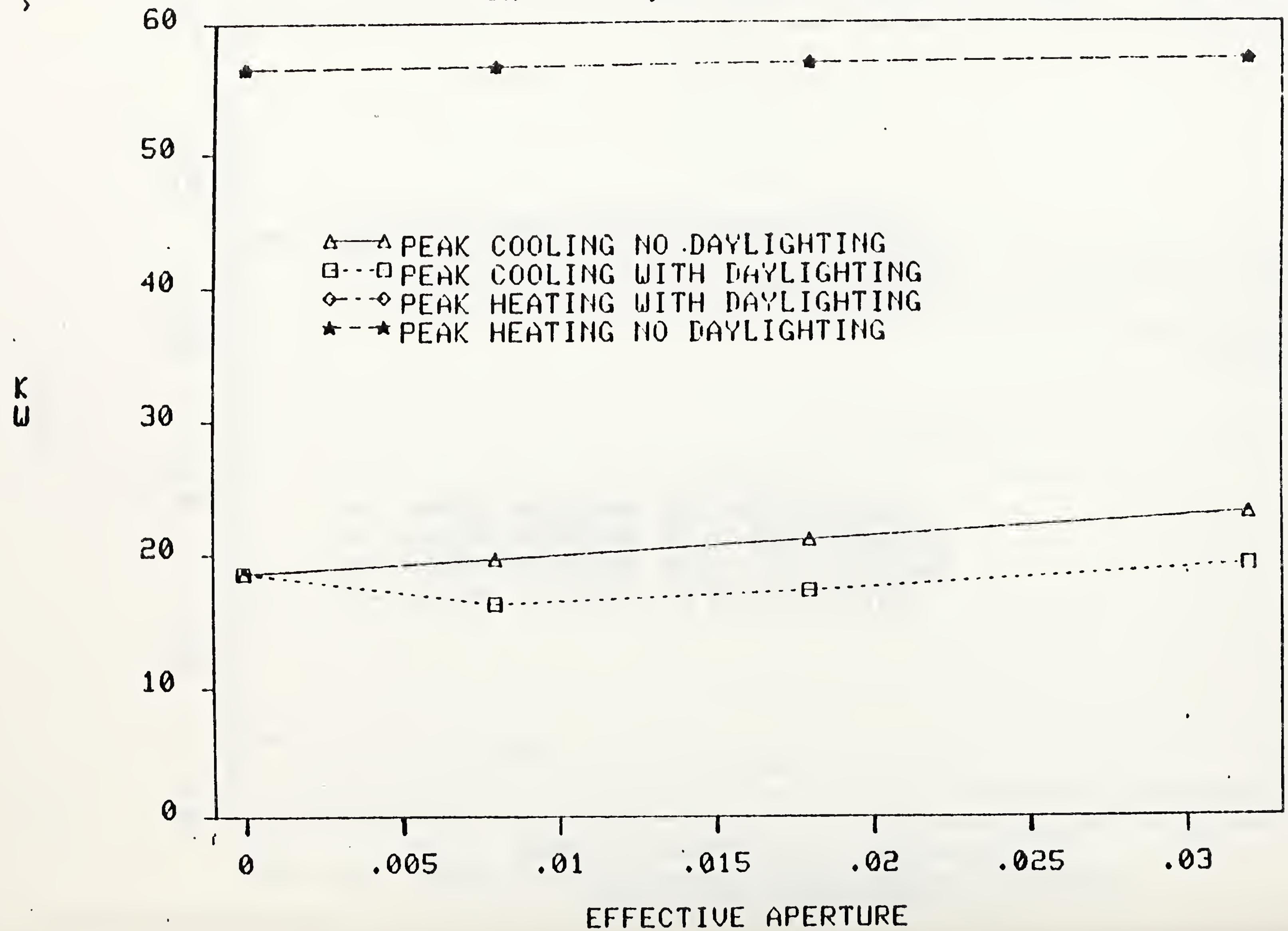


Figure 294. PEAK HEATING AND COOLING LOADS (Boston)
SOUTH SAWTOOTH, METAL FREESTANDING

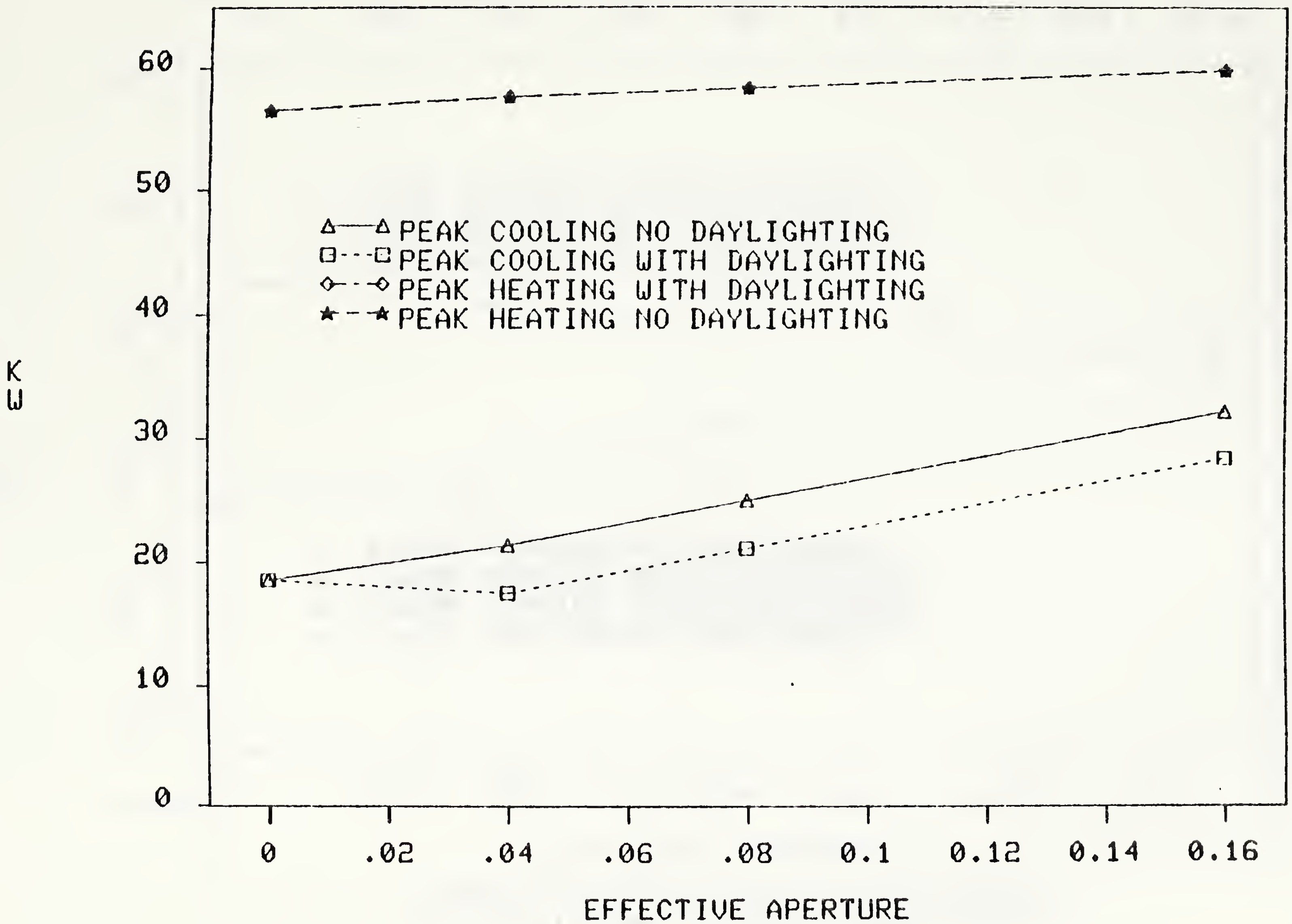


Figure 295. PEAK HEATING AND COOLING LOADS (Boston)
NORTH SAWTOOTH, METAL FREESTANDING

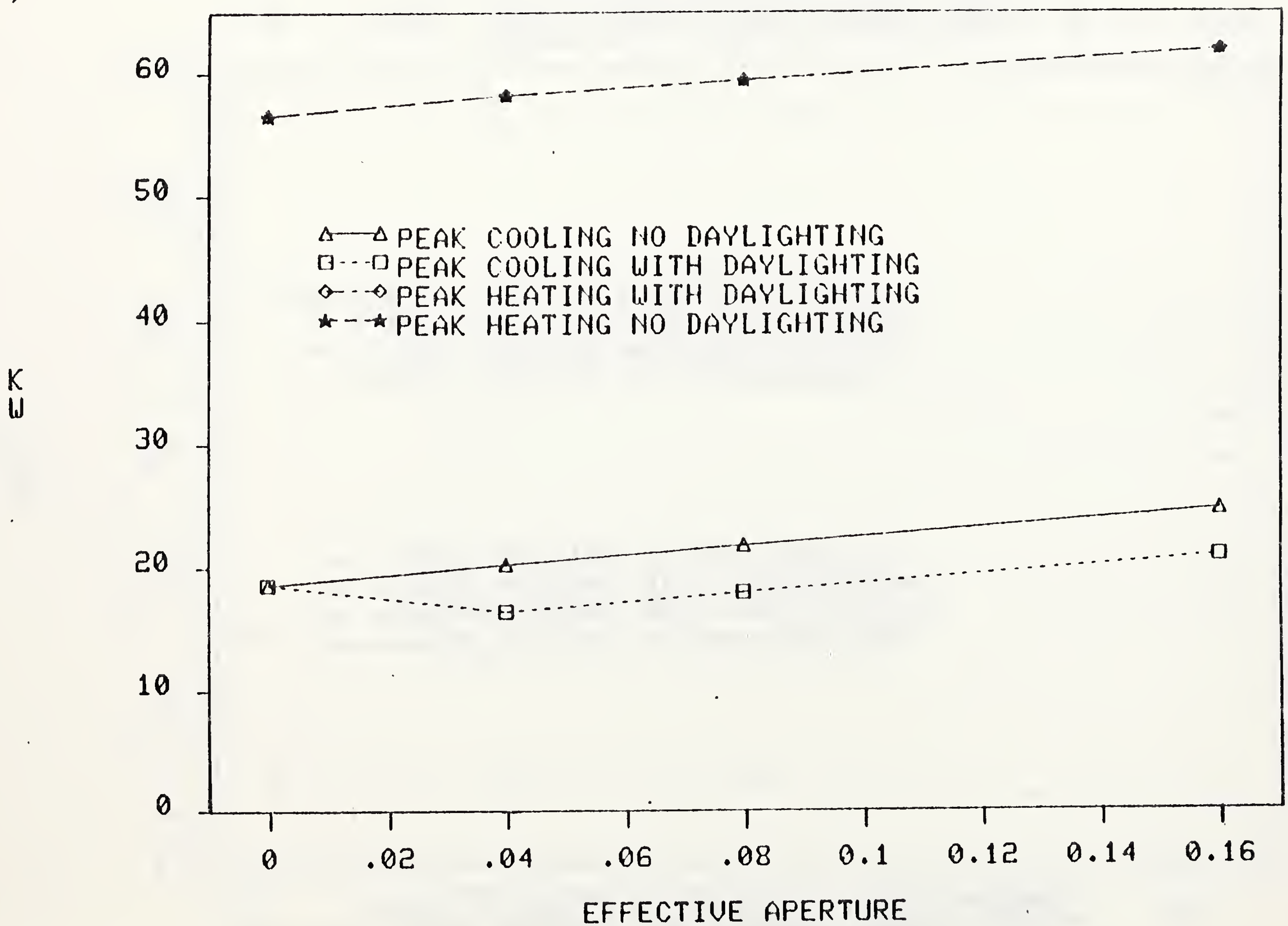


Figure 236. PEAK HEATING AND COOLING LOADS (Boston)
SOUTH WINDOW, METAL FREESTANDING

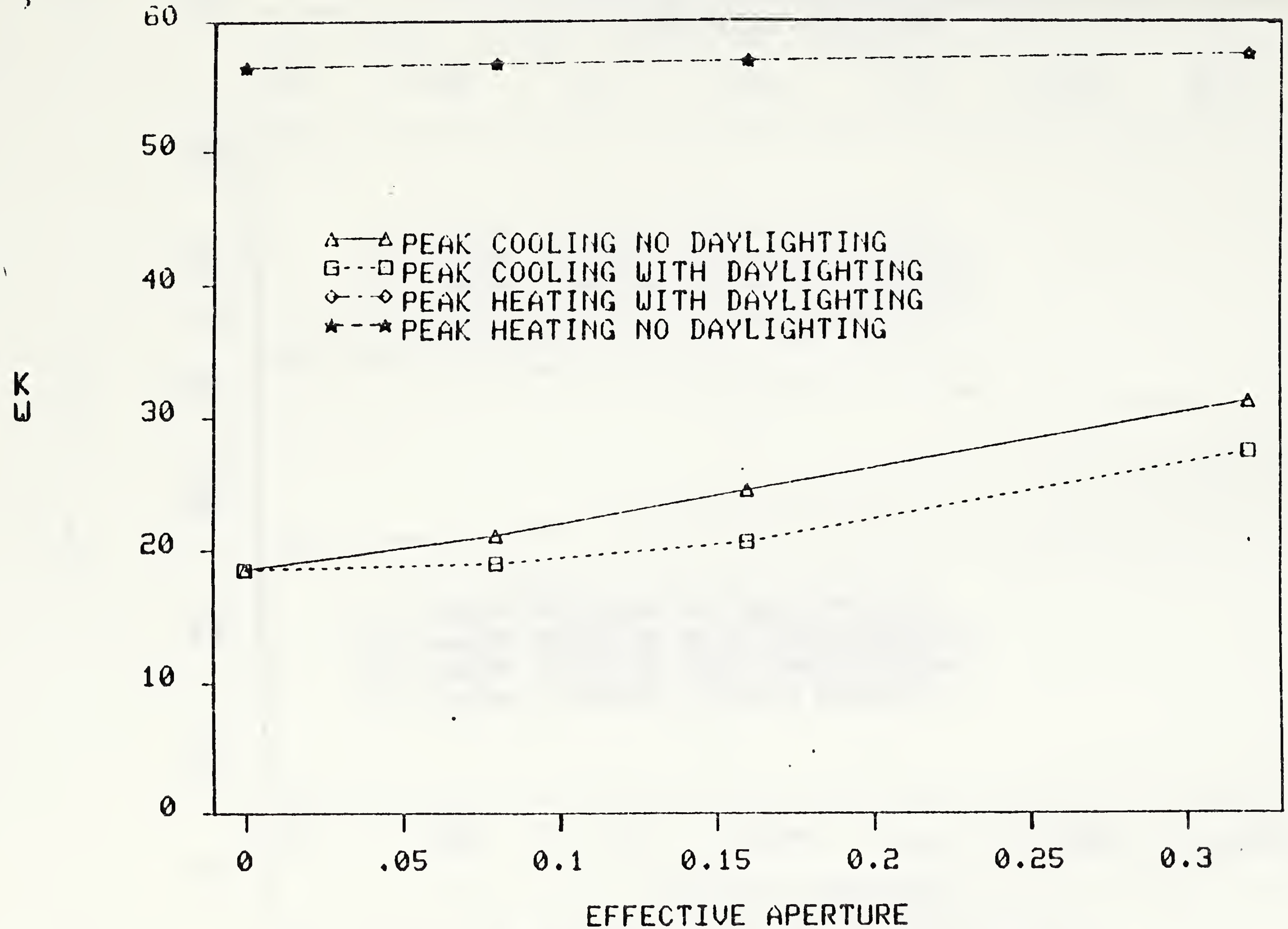


Figure 297. PEAK HEATING AND COOLING LOADS (Boston)
NORTH WINDOW, METAL FREESTANDING

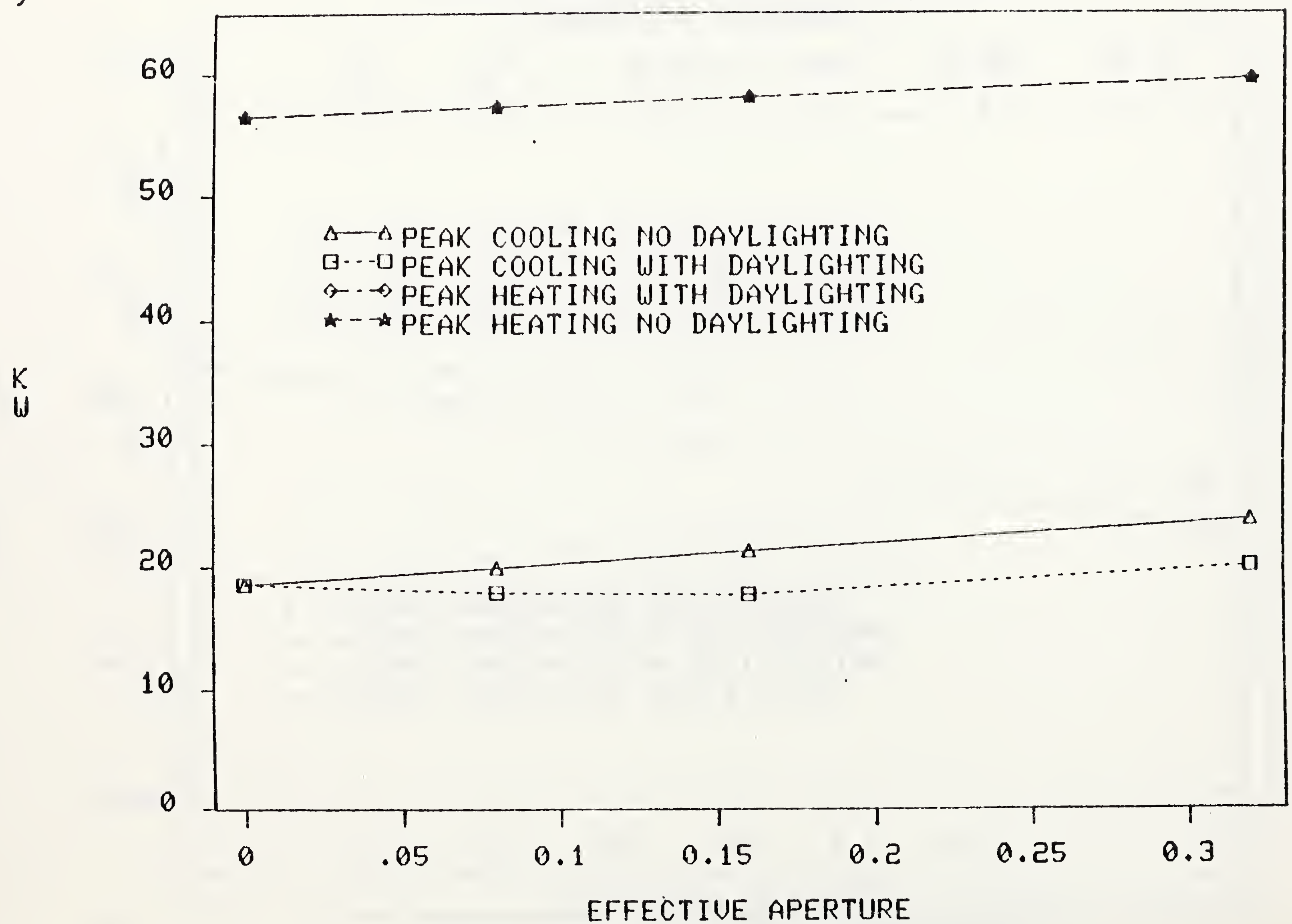


Figure 298. PEAK HEATING AND COOLING LOADS (Boston)
SKYLIGHTS, METAL ATTACHED

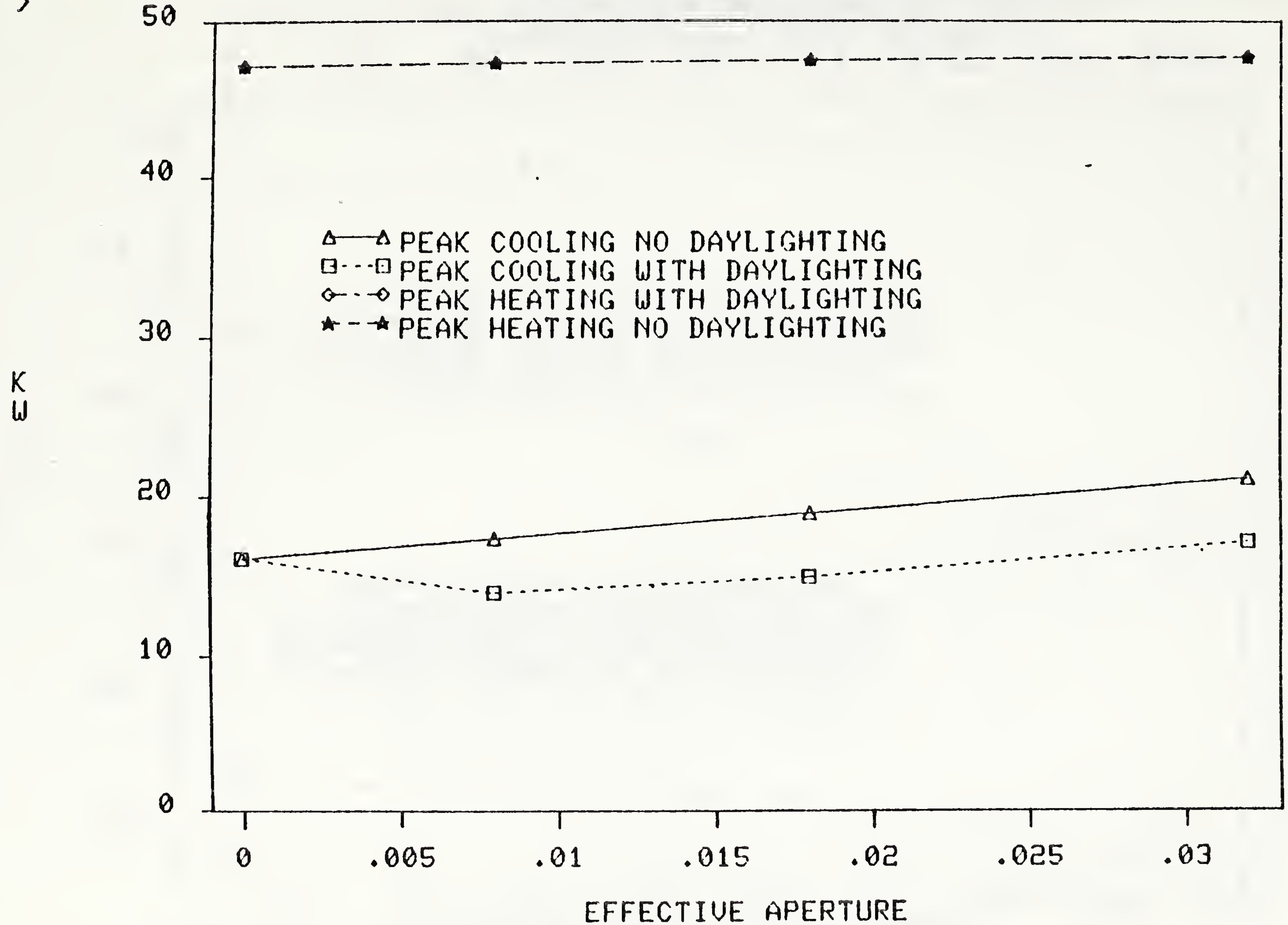


Figure 299. PEAK HEATING AND COOLING LOADS (Boston)
SOUTH SAWTOOTH, METAL ATTACHED

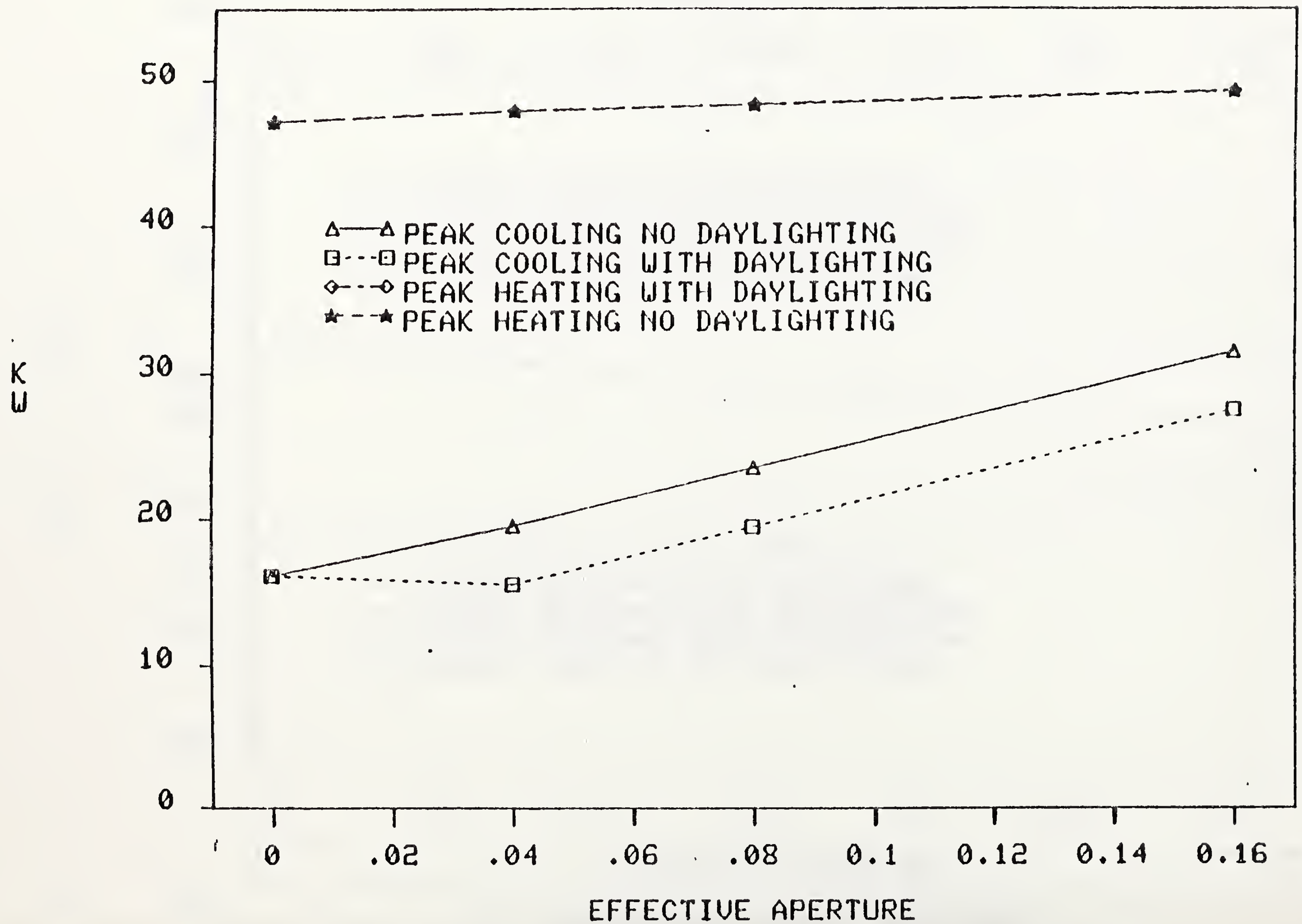


Figure 300. PEAK HEATING AND COOLING LOADS (Boston)
NORTH SAWTOOTH, METAL ATTACHED

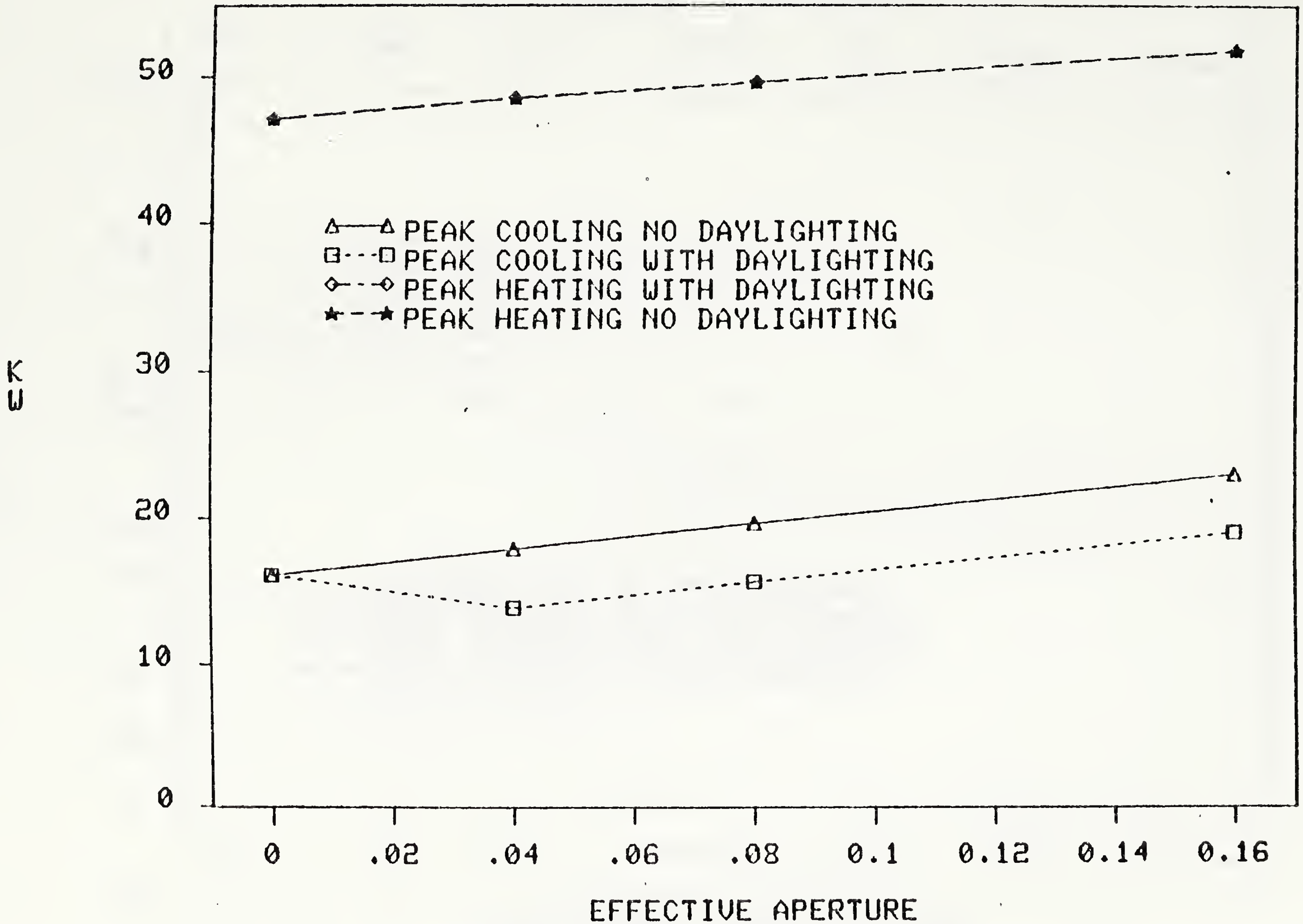


Figure 301. PEAK HEATING AND COOLING LOADS (Boston)
SOUTH WINDOW, METAL ATTACHED

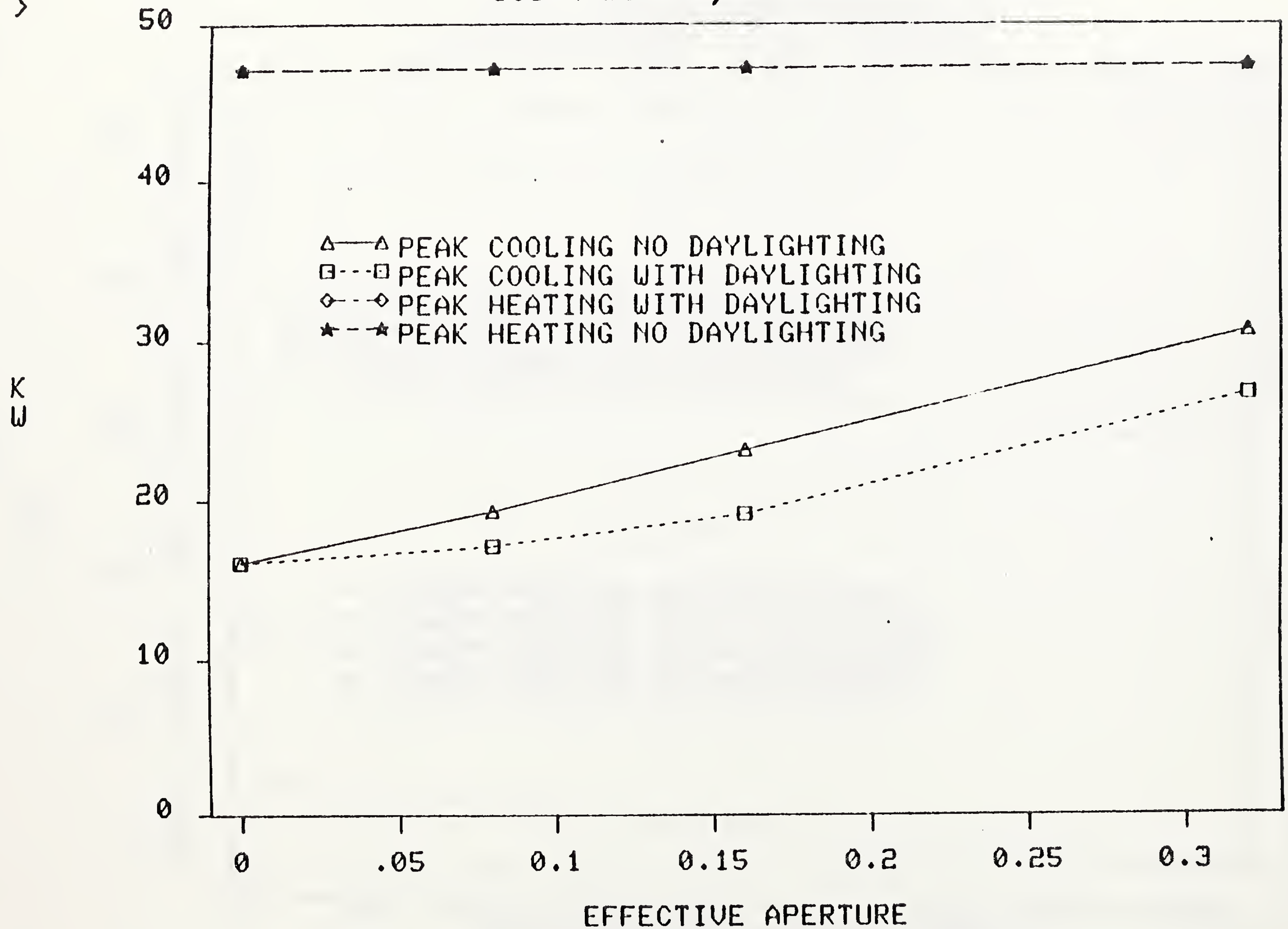


Figure 302. PEAK HEATING AND COOLING LOADS (Boston)
NORTH WINDOW, METAL ATTACHED

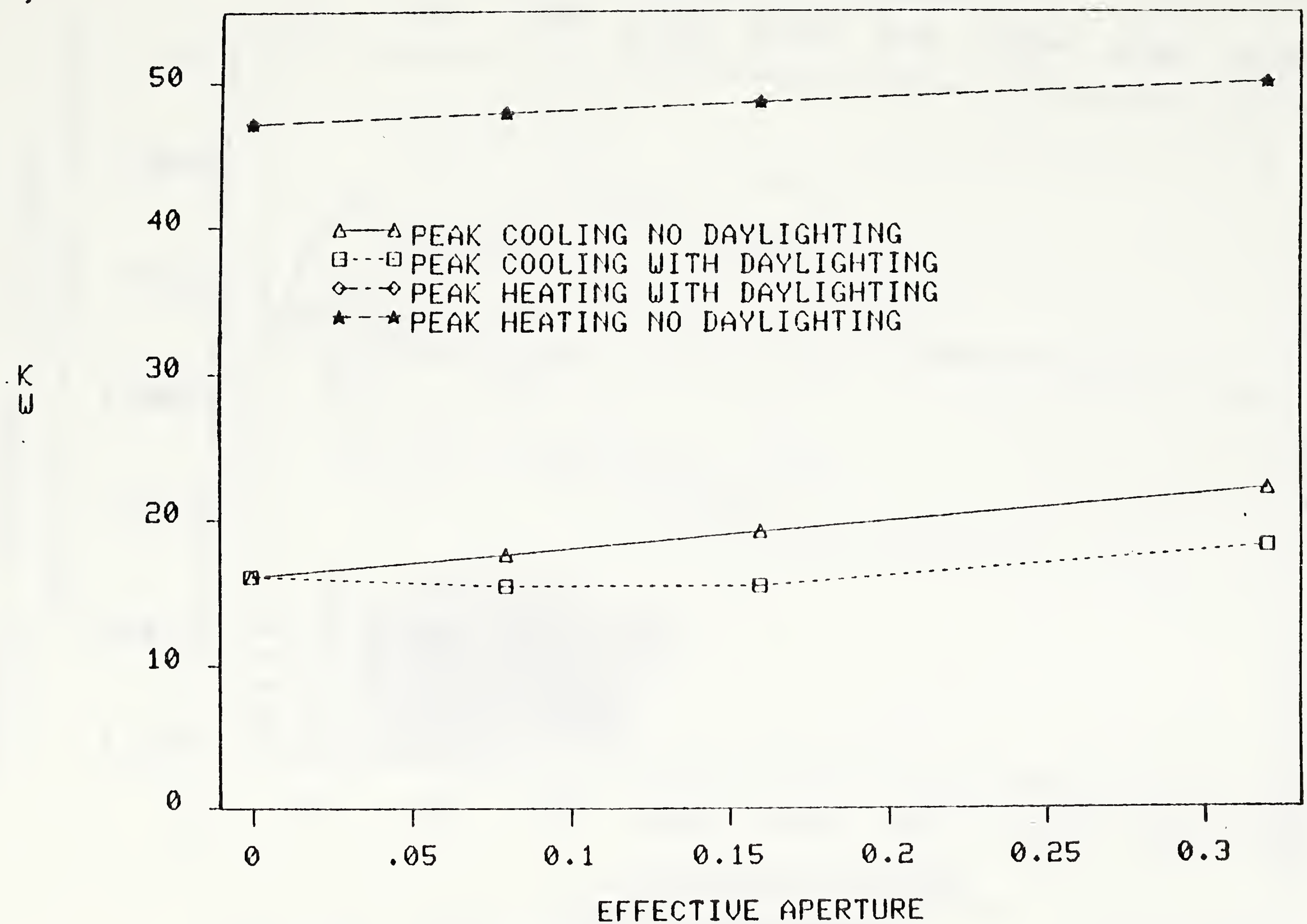


Figure 303. TOTAL ENERGY WITH DAYLIGHT (Seattle)
BRICK FREESTANDING

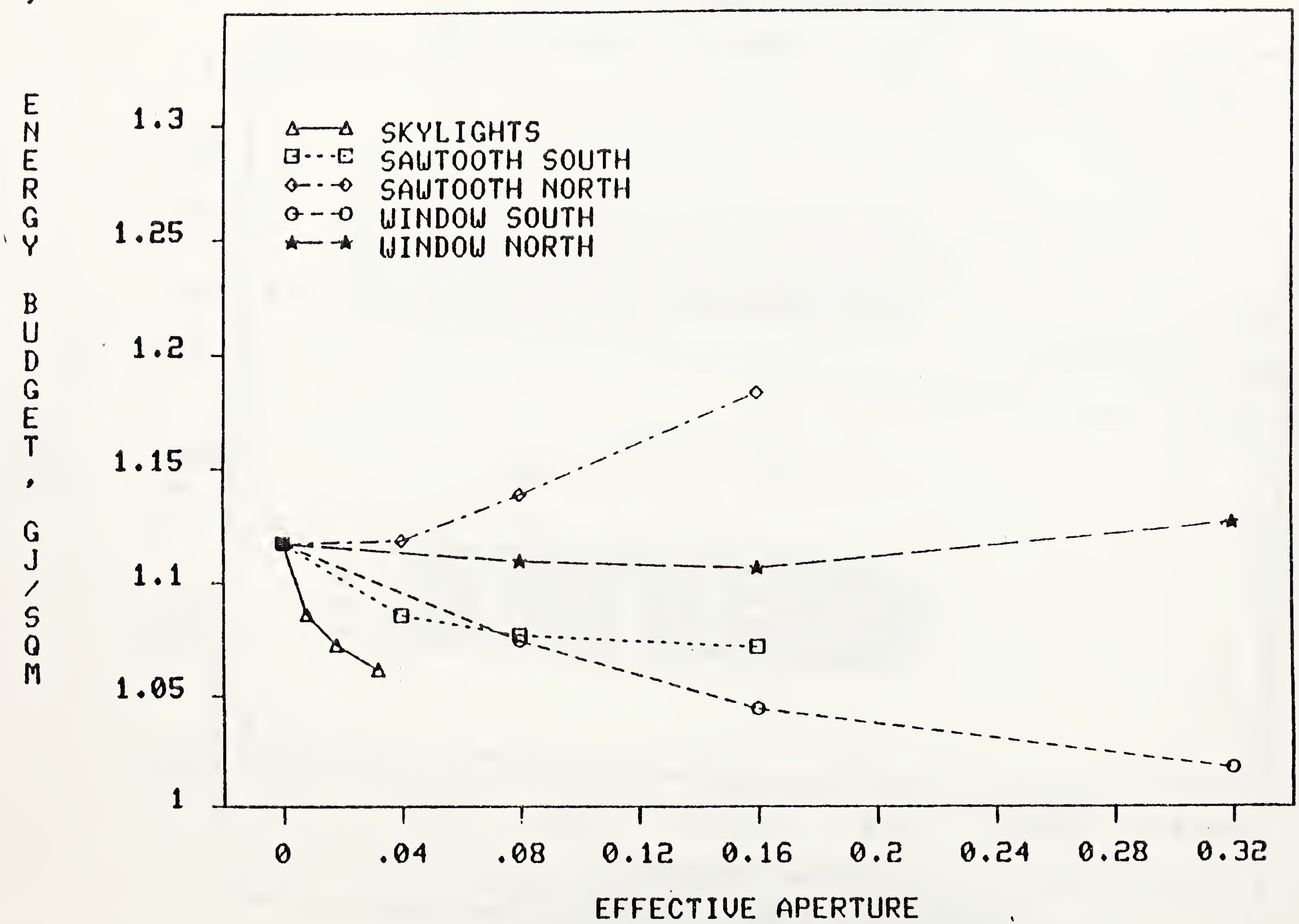


Figure 304. TOTAL ENERGY WITH DAYLIGHT (Seattle)
BRICK ATTACHED

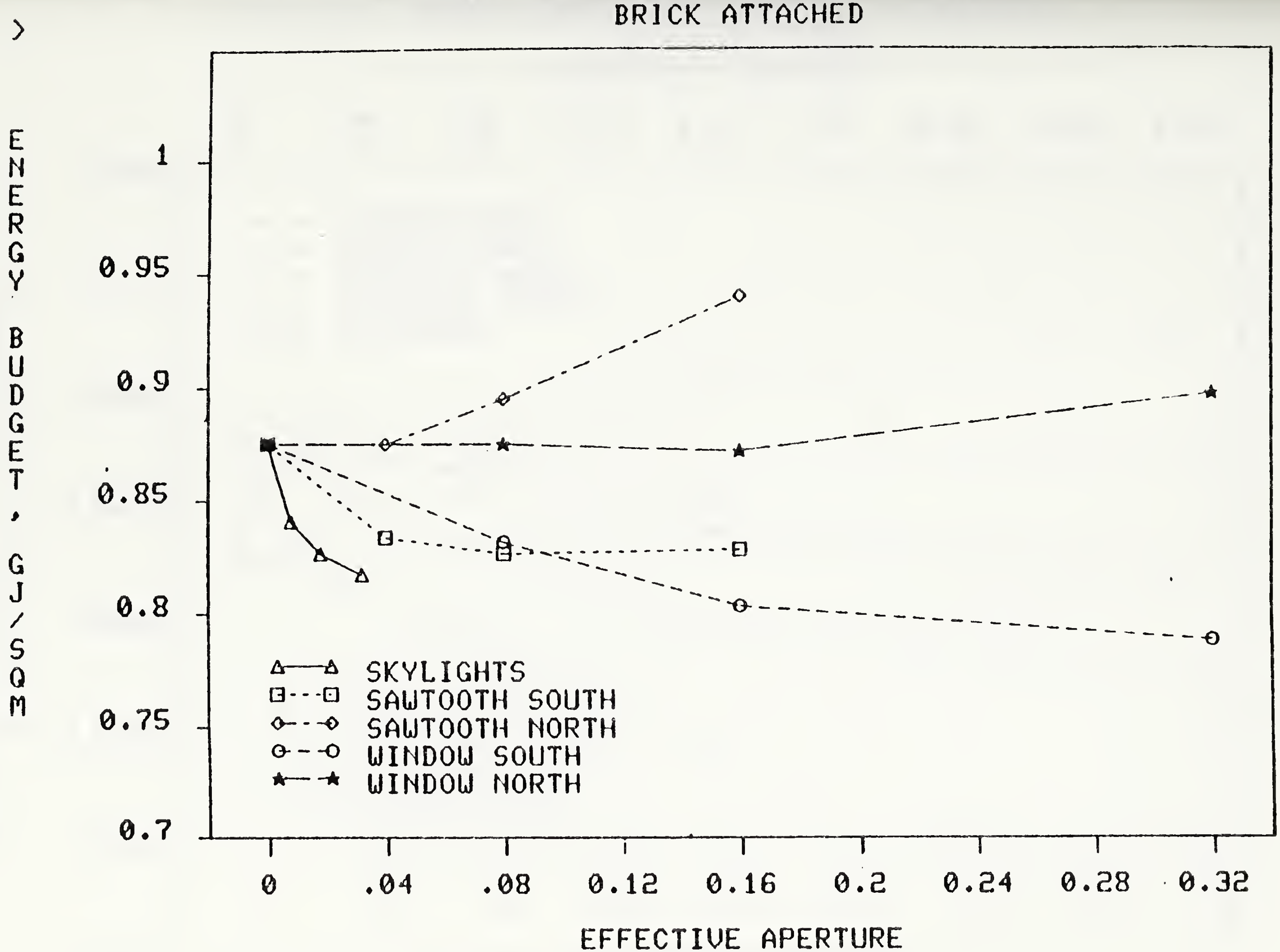


Figure 305. TOTAL ENERGY WITH DAYLIGHT (Seattle)
METAL FREESTANDING

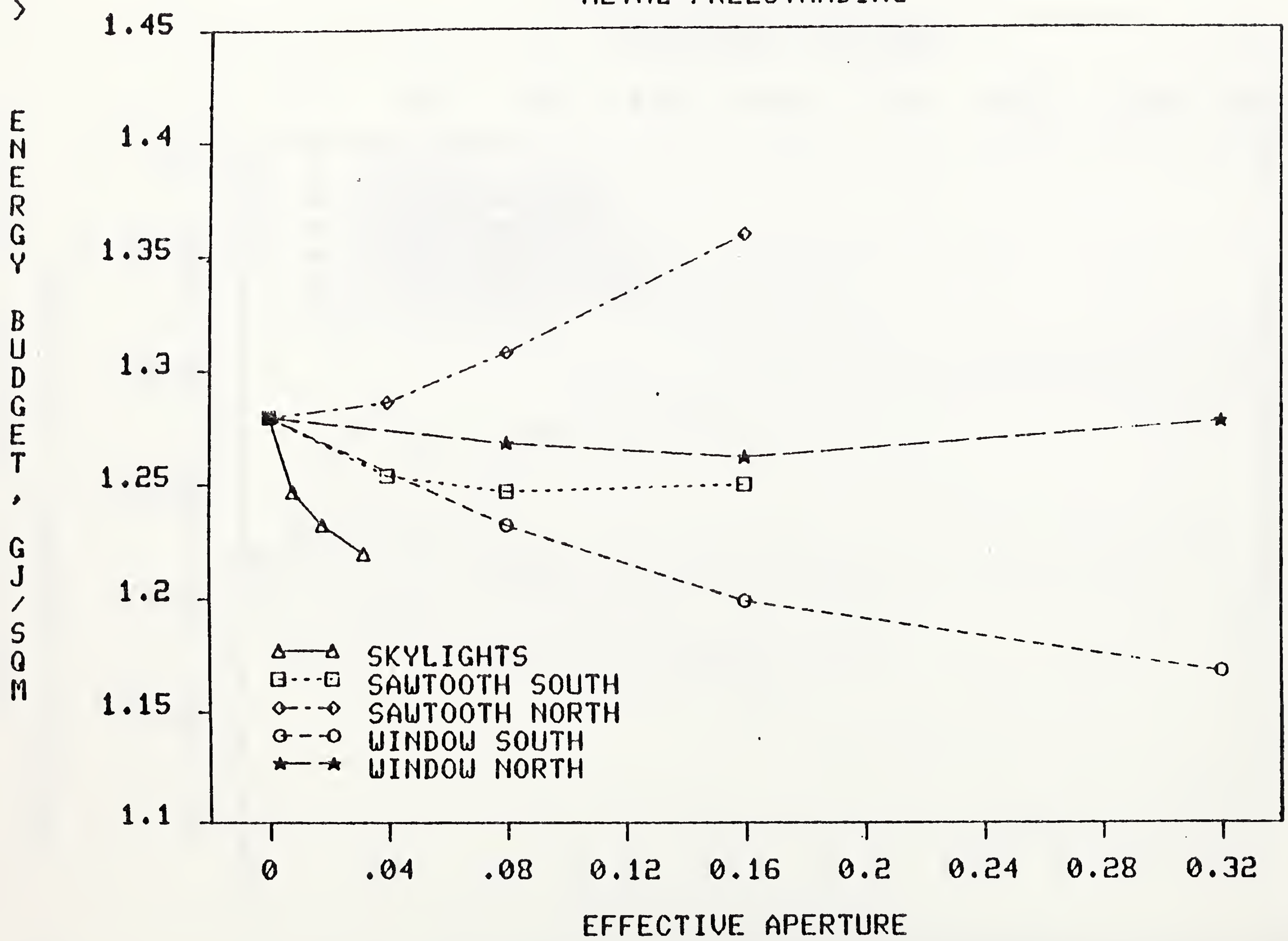


Figure 306. TOTAL ENERGY WITH DAYLIGHT (Seattle)
METAL ATTACHED

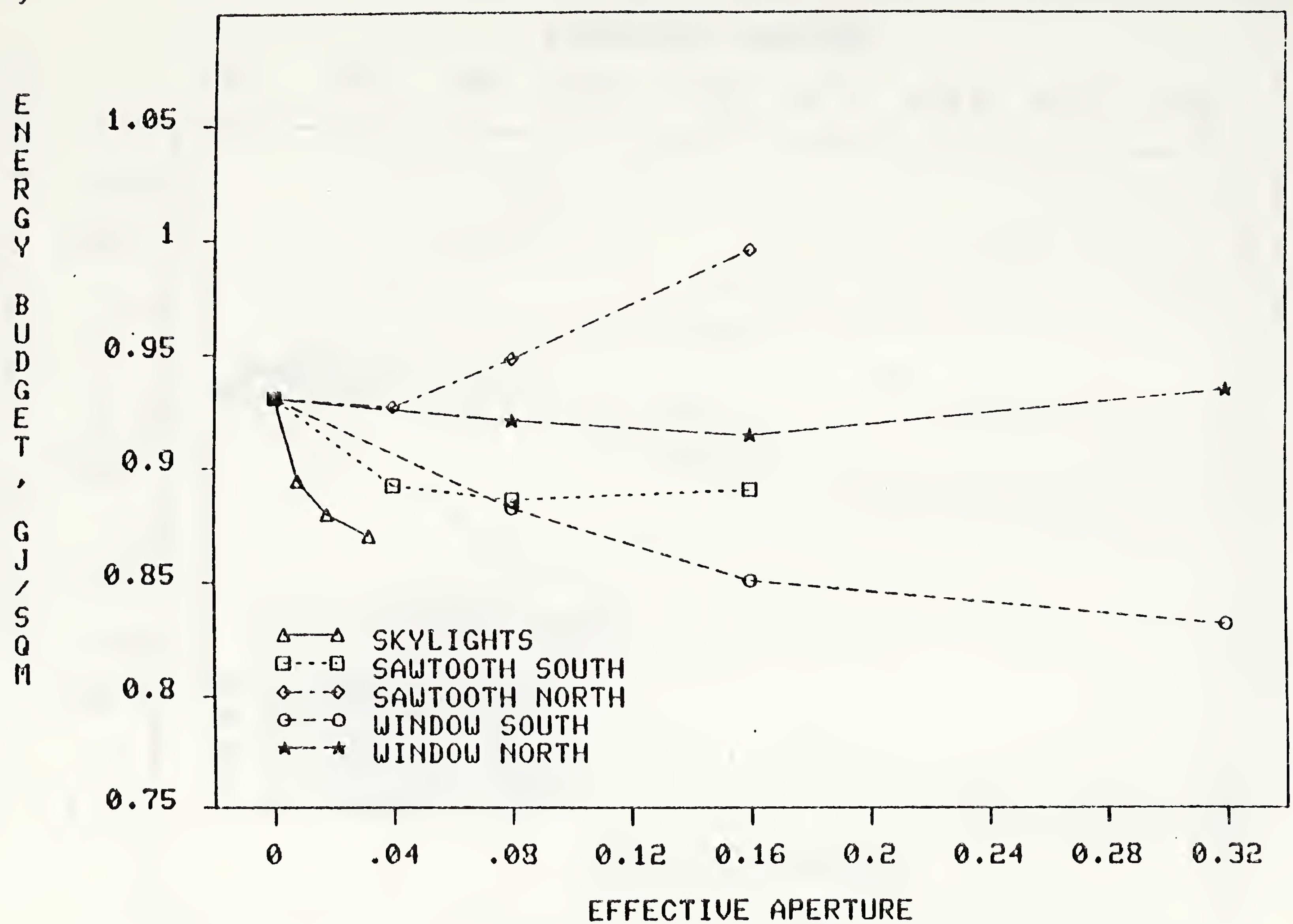


Figure 307. TOTAL ENERGY WITHOUT DAYLIGHT (Seattle) BRICK FREESTANDING

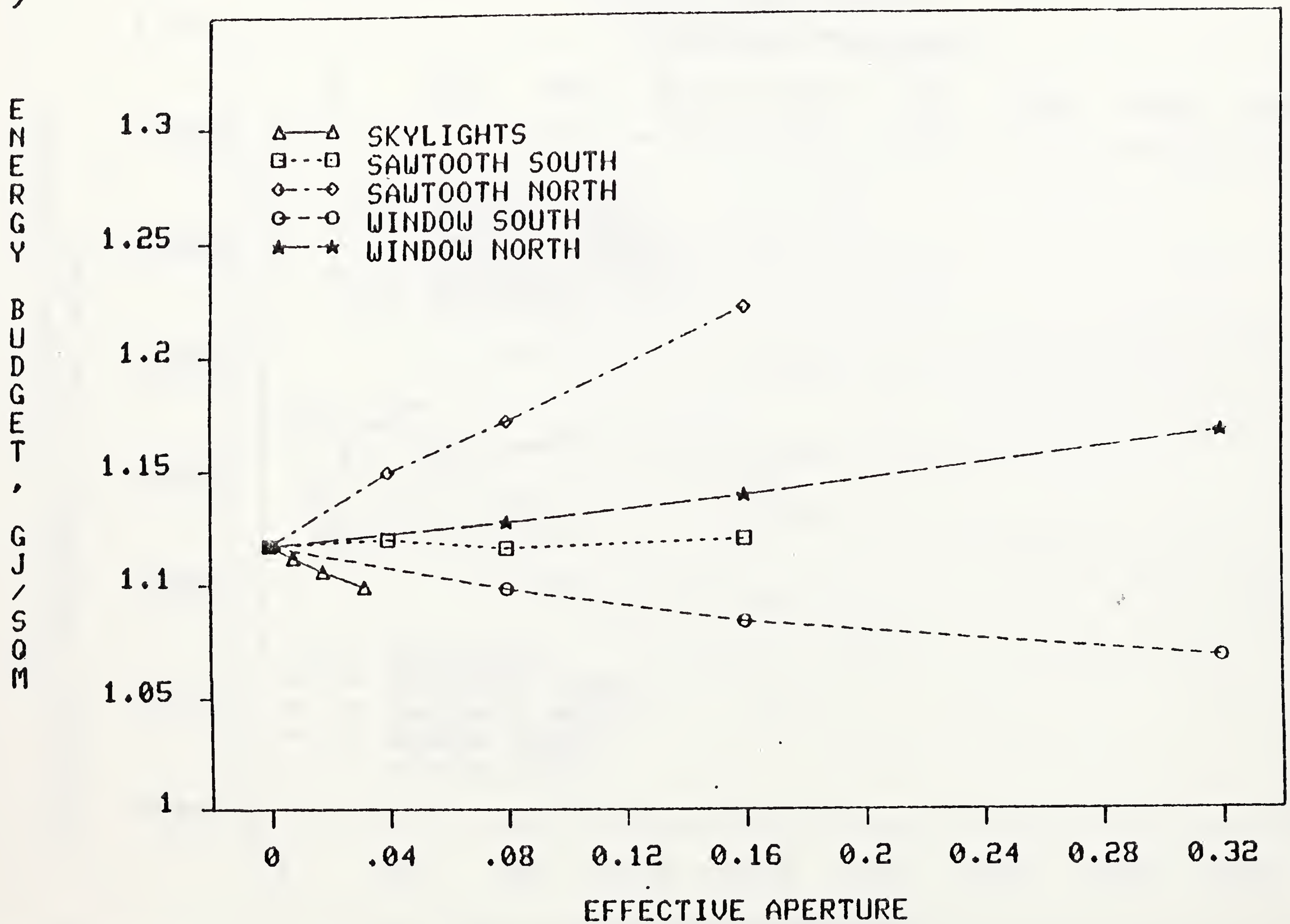


Figure 308. TOTAL ENERGY WITHOUT DAYLIGHT
BRICK ATTACHED

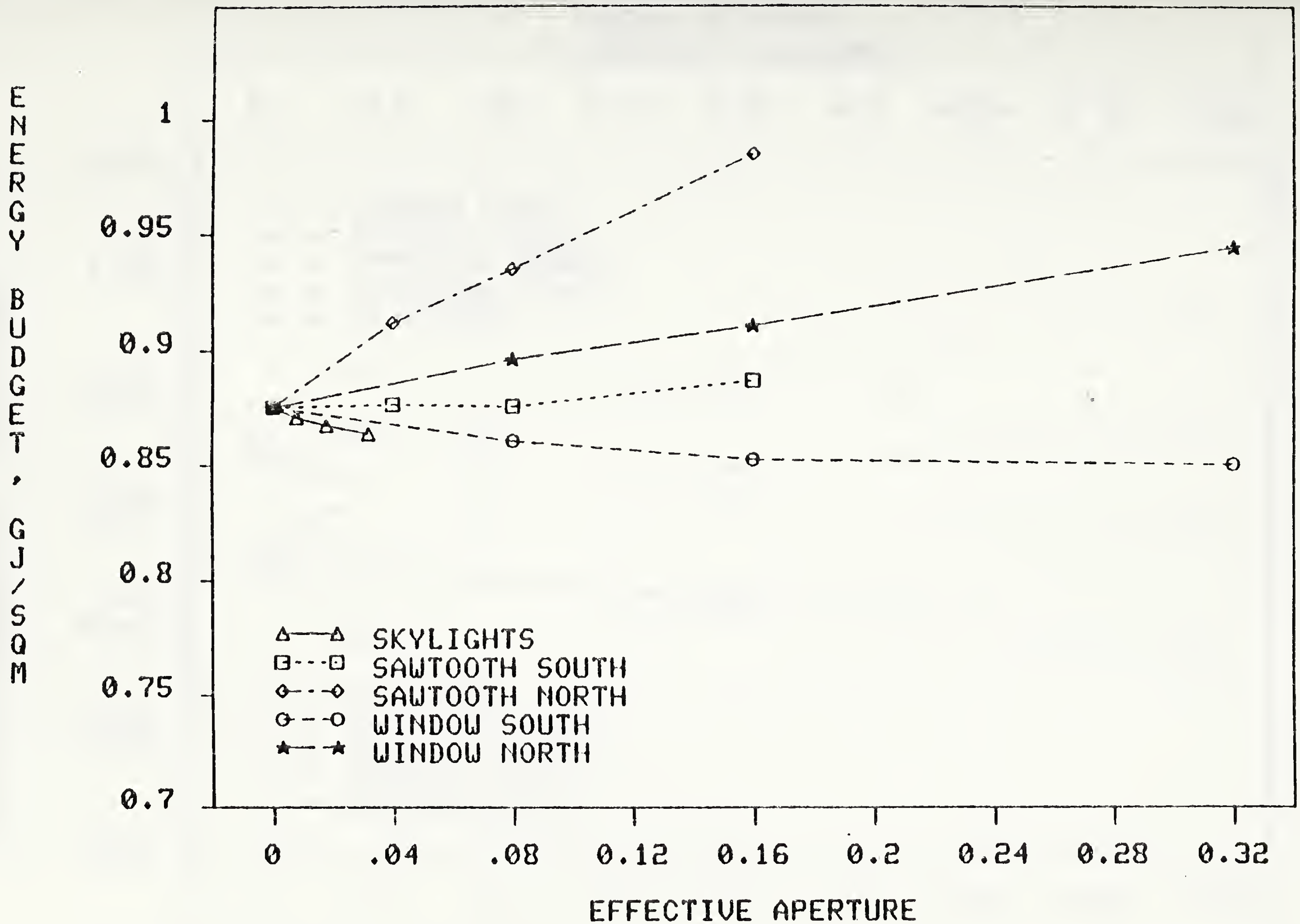


Figure 309. TOTAL ENERGY WITHOUT DAYLIGHT (Seattle)
METAL FREESTANDING

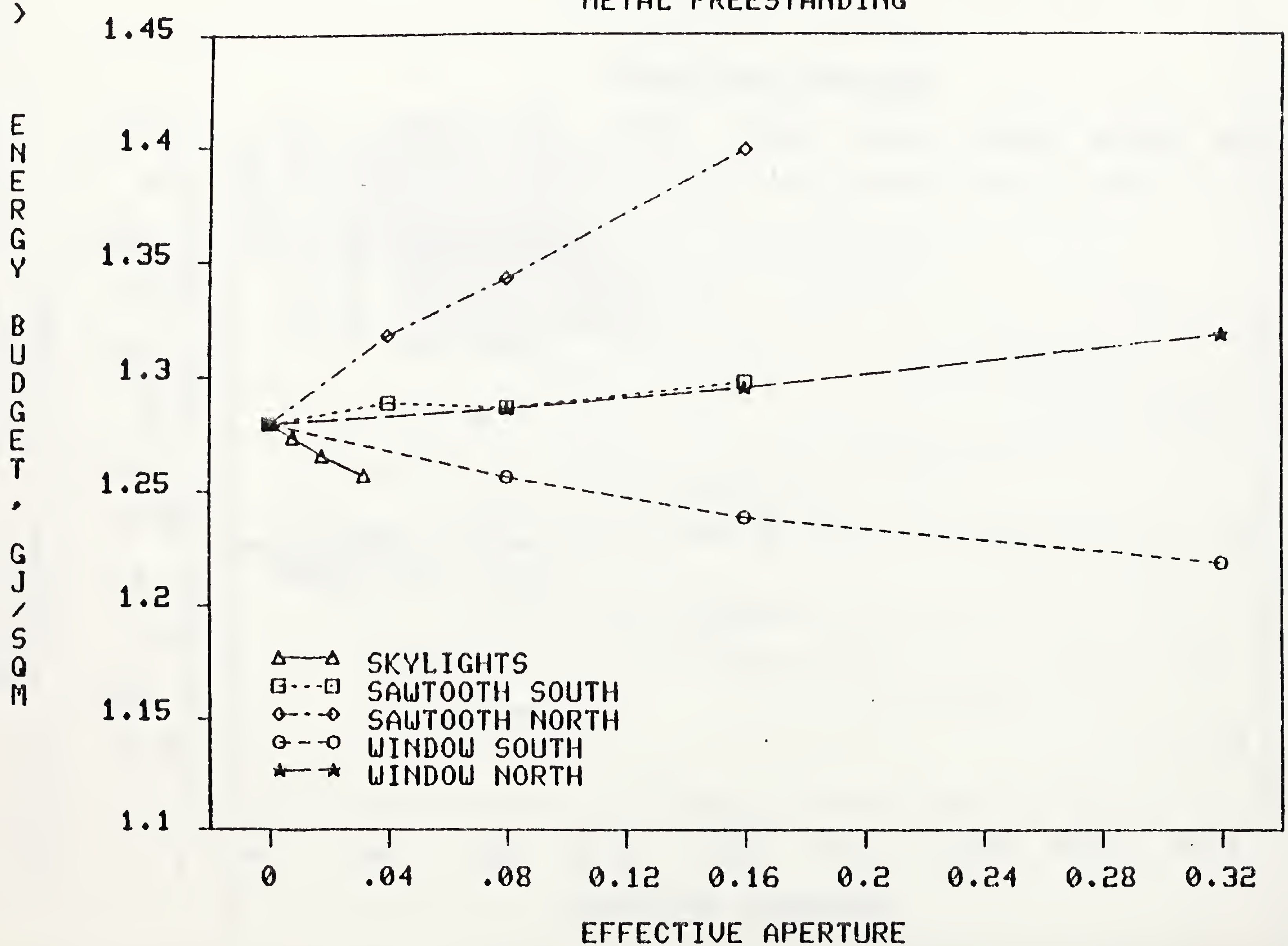


Figure 310. TOTAL ENERGY WITHOUT DAYLIGHT (Seattle)
METAL ATTACHED

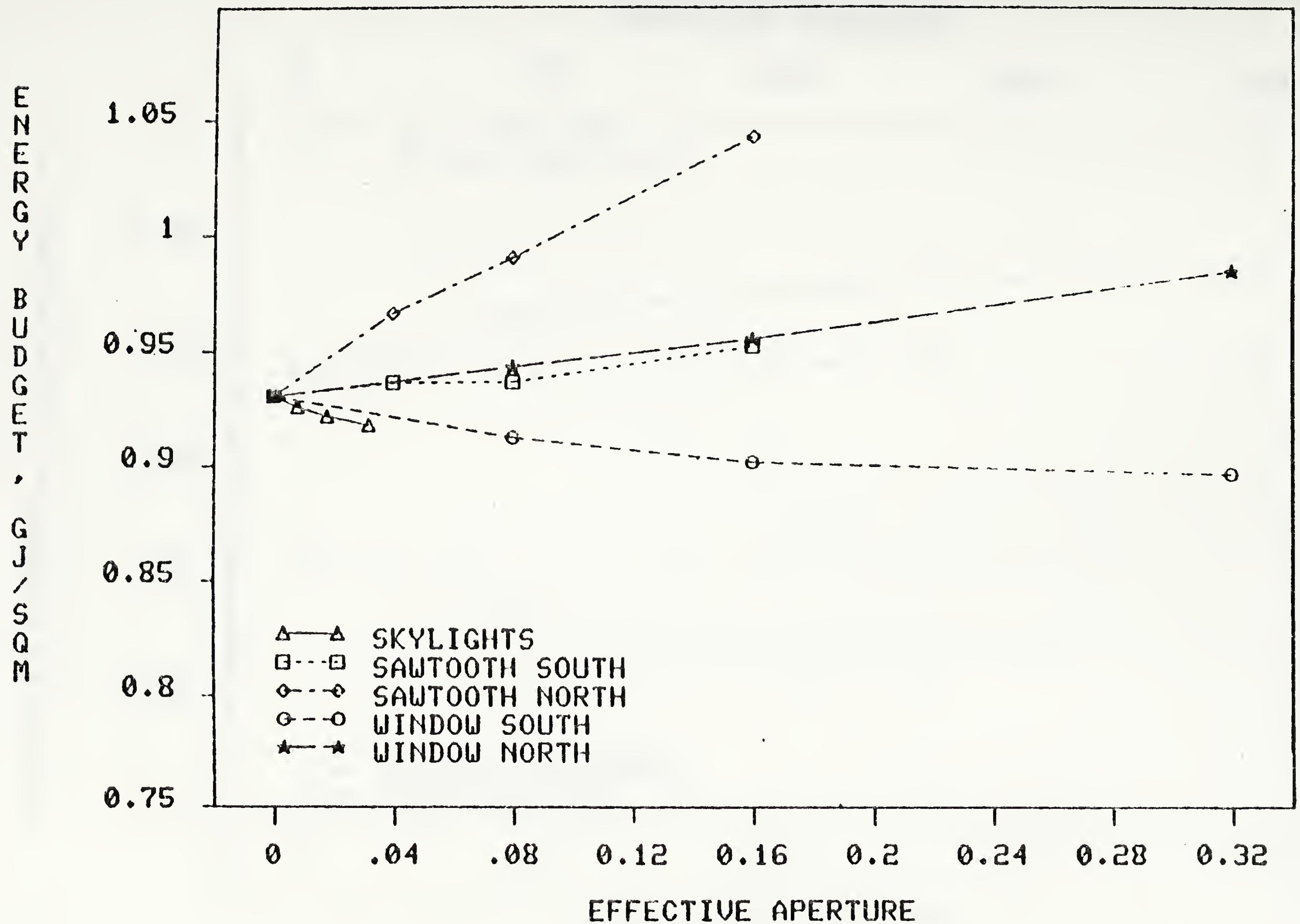


Figure 311. TOTAL ENERGY - SKYLIGHTS (Seattle)
BRICK FREESTANDING

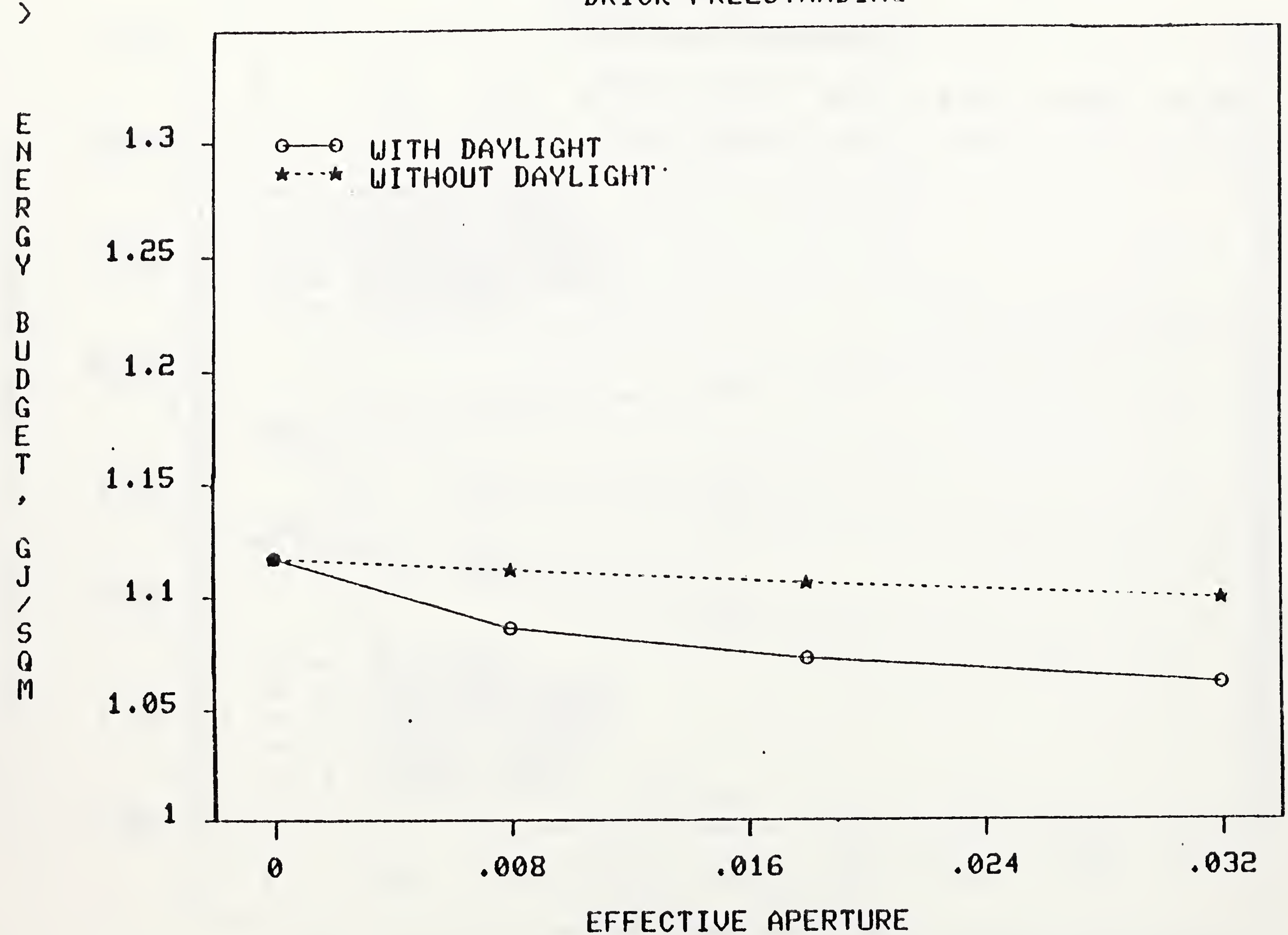


Figure 312. TOTAL ENERGY - SOUTH SAWTOOTH (Seattle)
BRICK FREESTANDING

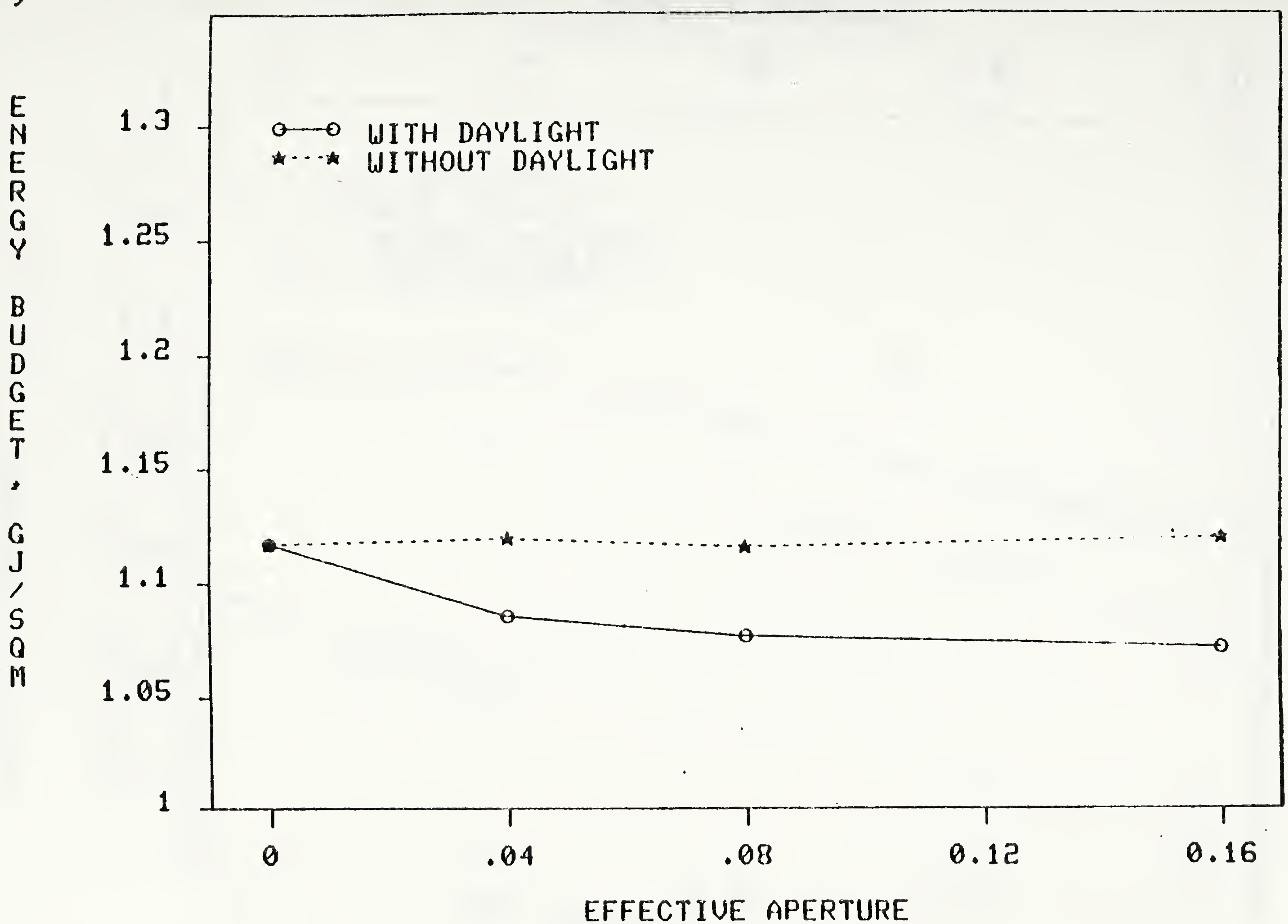


Figure 313. TOTAL ENERGY - NORTH SAWTOOTH (Seattle)
BRICK FREESTANDING

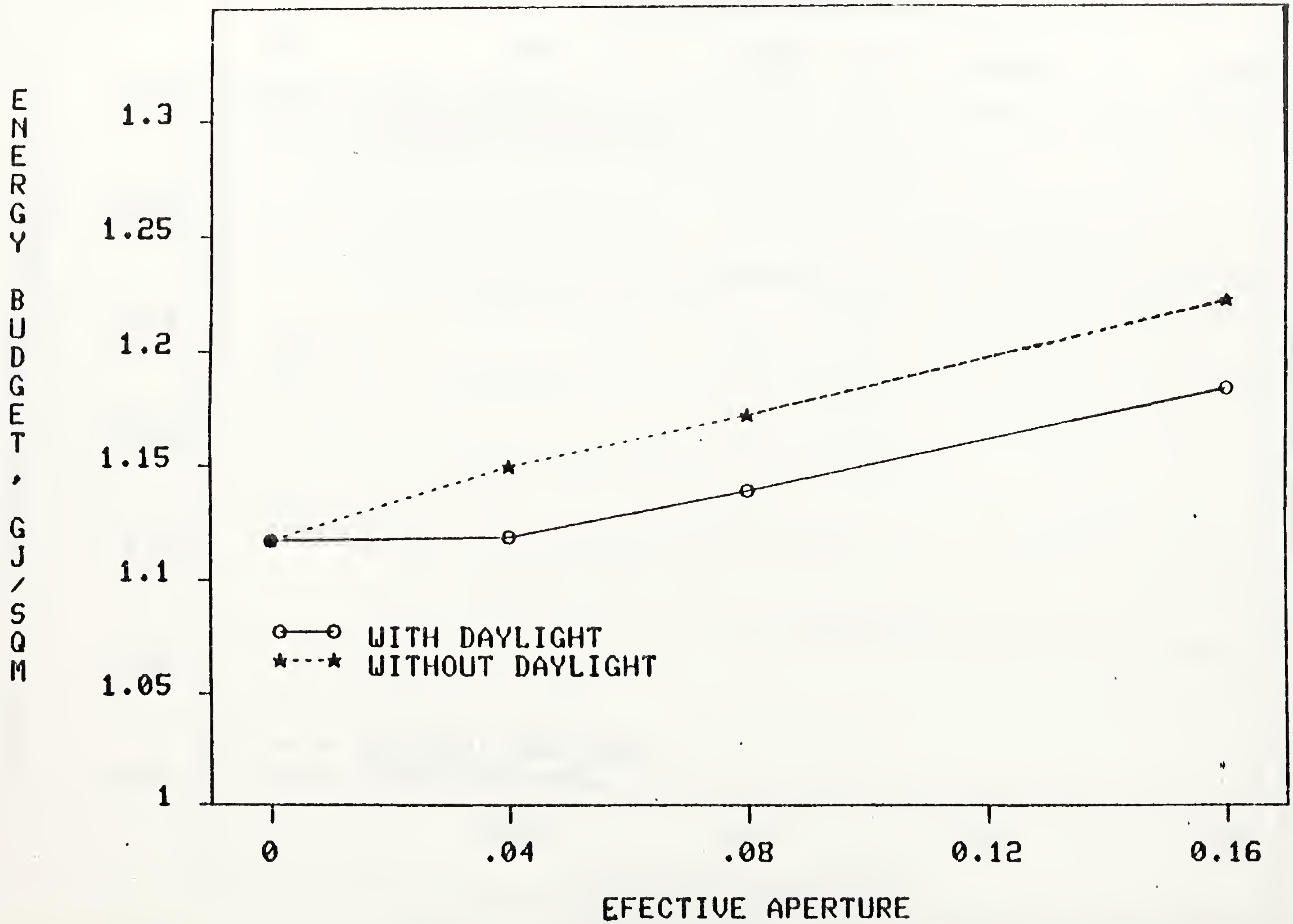


Figure 314. TOTAL ENERGY - SOUTH WINDOW (Seattle)
BRICK FREESTANDING

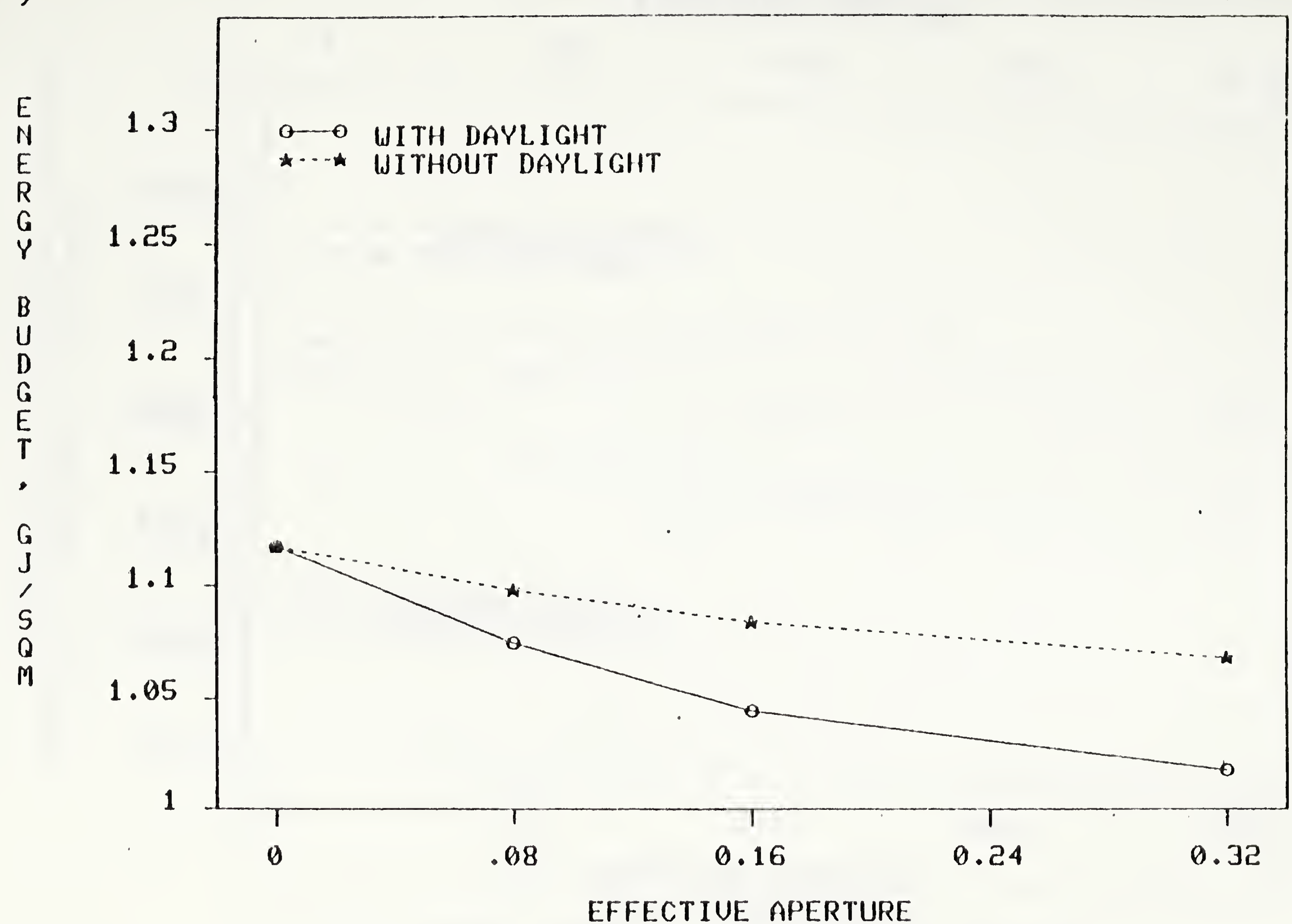


Figure 315. TOTAL ENERGY - NORTH WINDOW (Seattle)
BRICK FREESTANDING

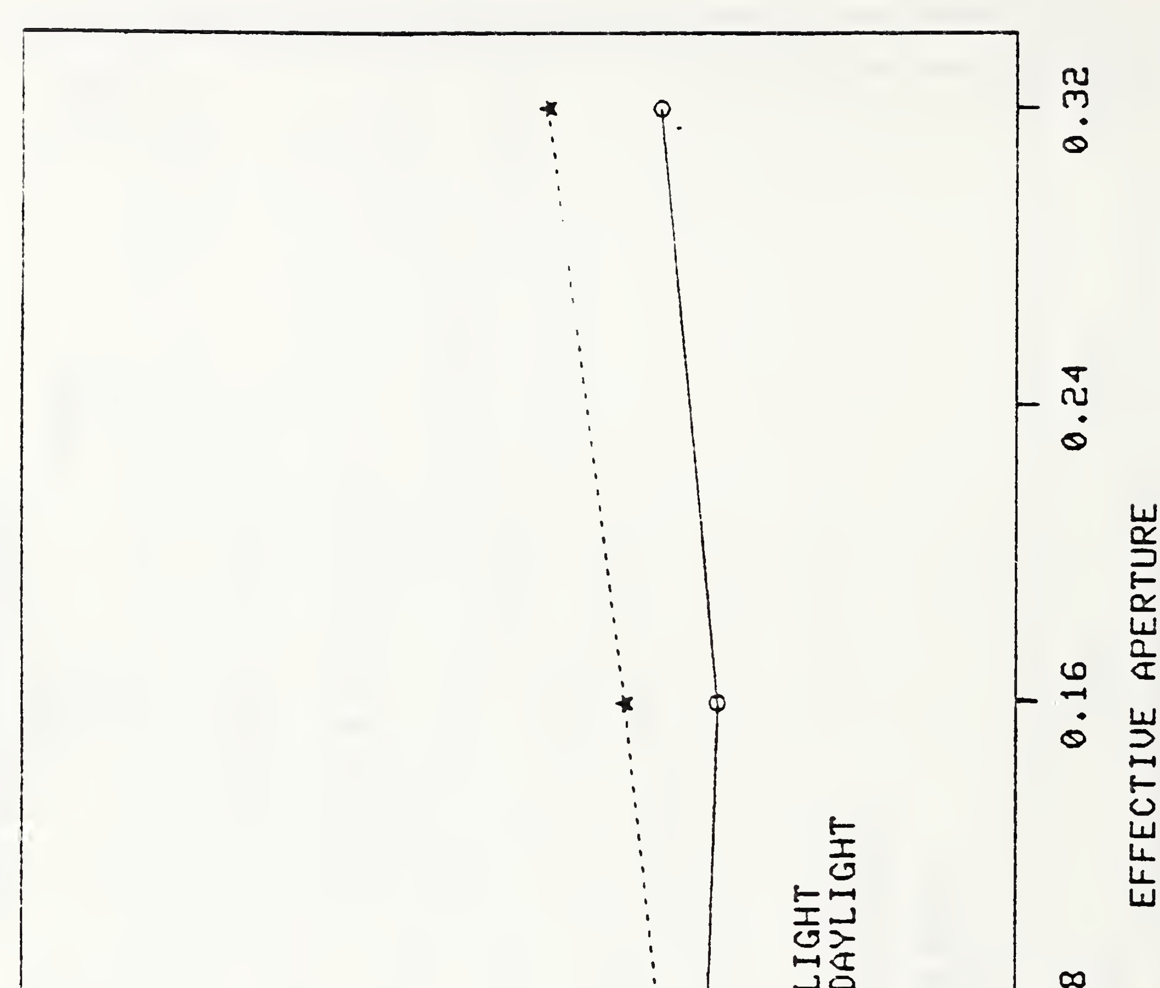


Figure 316. TOTAL ENERGY - SKYLIGHTS (Seattle)
BRICK ATTACHED

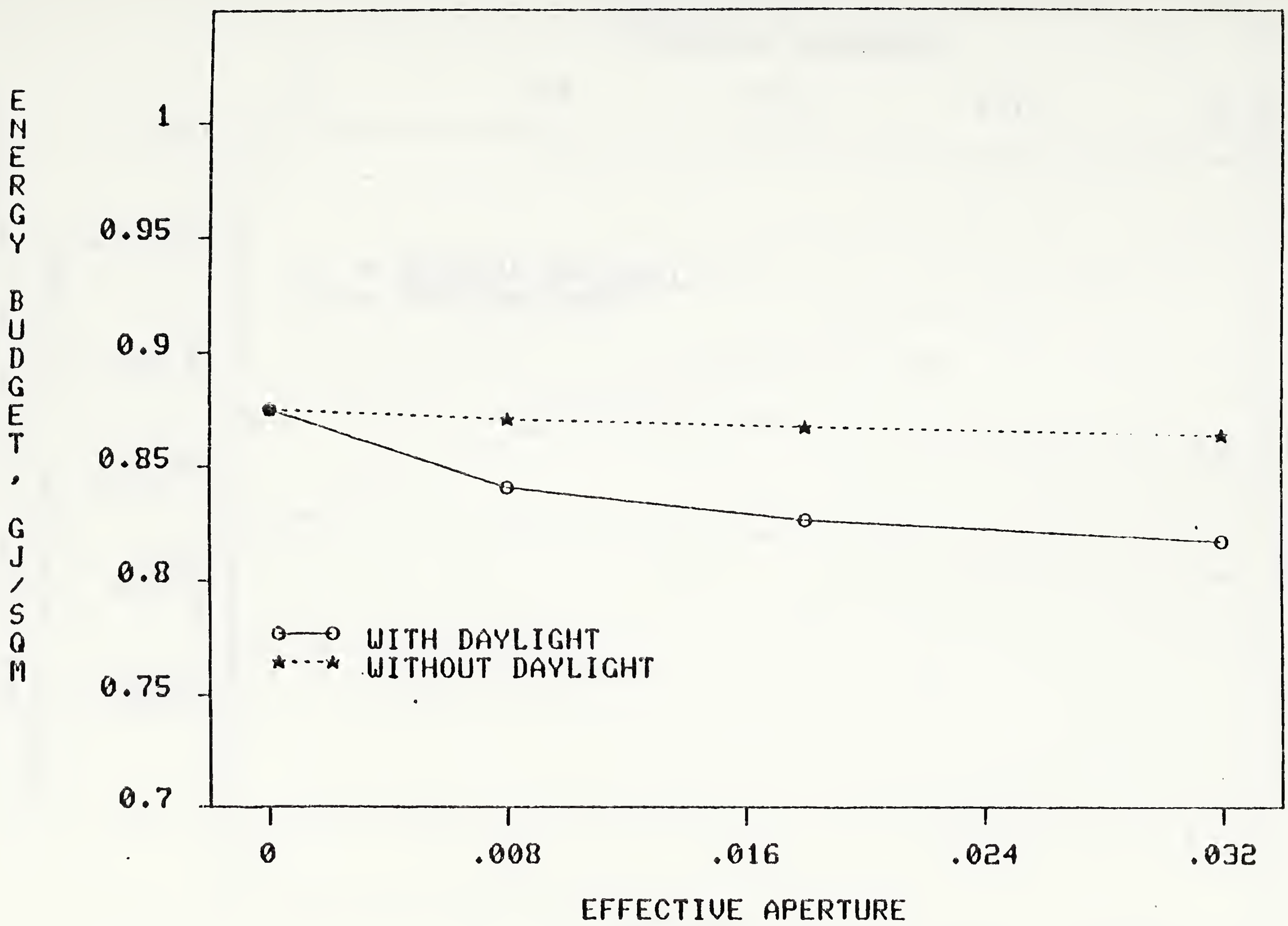


Figure 317. TOTAL ENERGY - SOUTH SAWTOOTH (Seattle)
BRICK ATTACHED

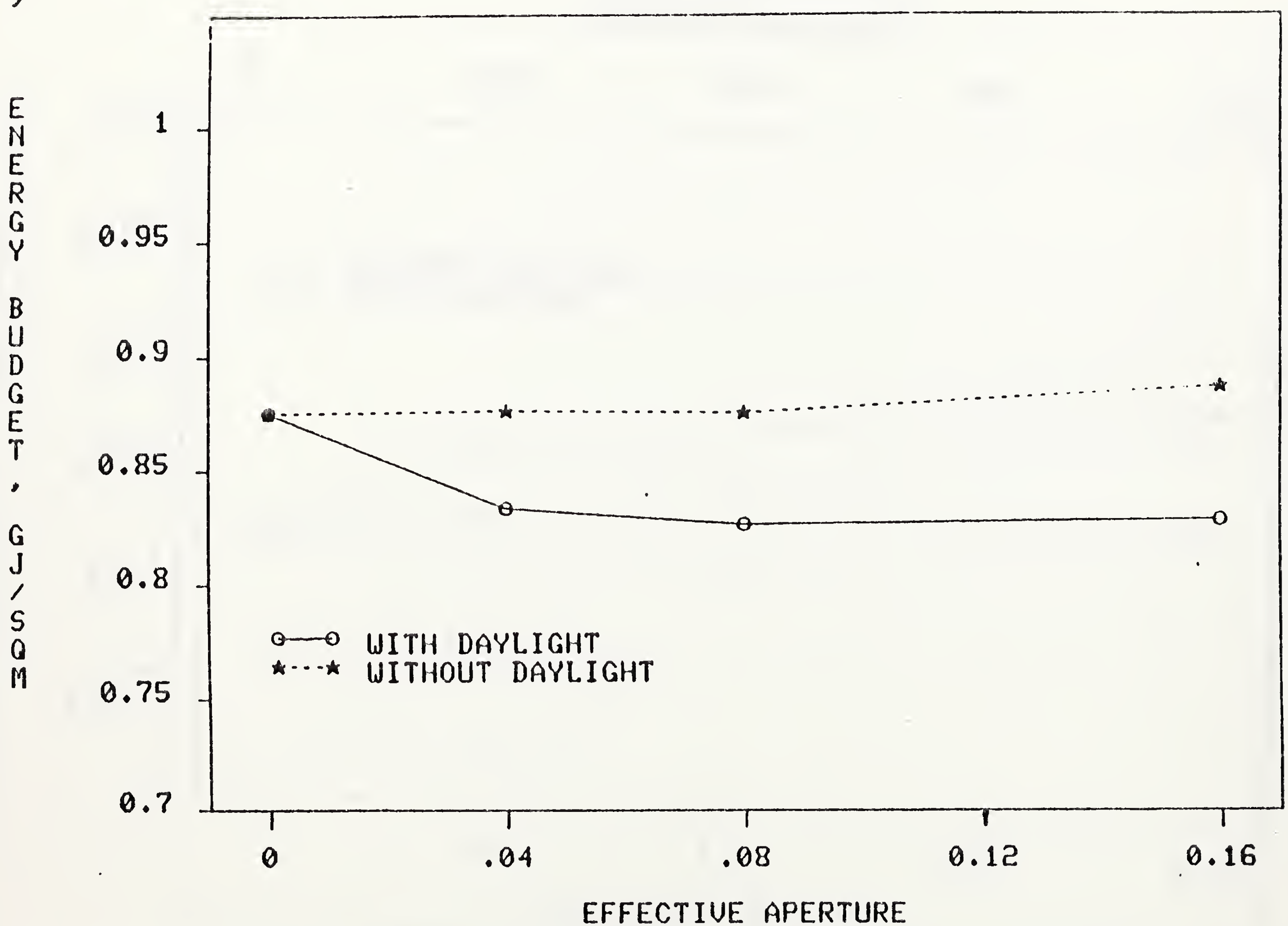


Figure 318. TOTAL ENERGY - NORTH SAWTOOTH (Seattle)
BRICK ATTACHED

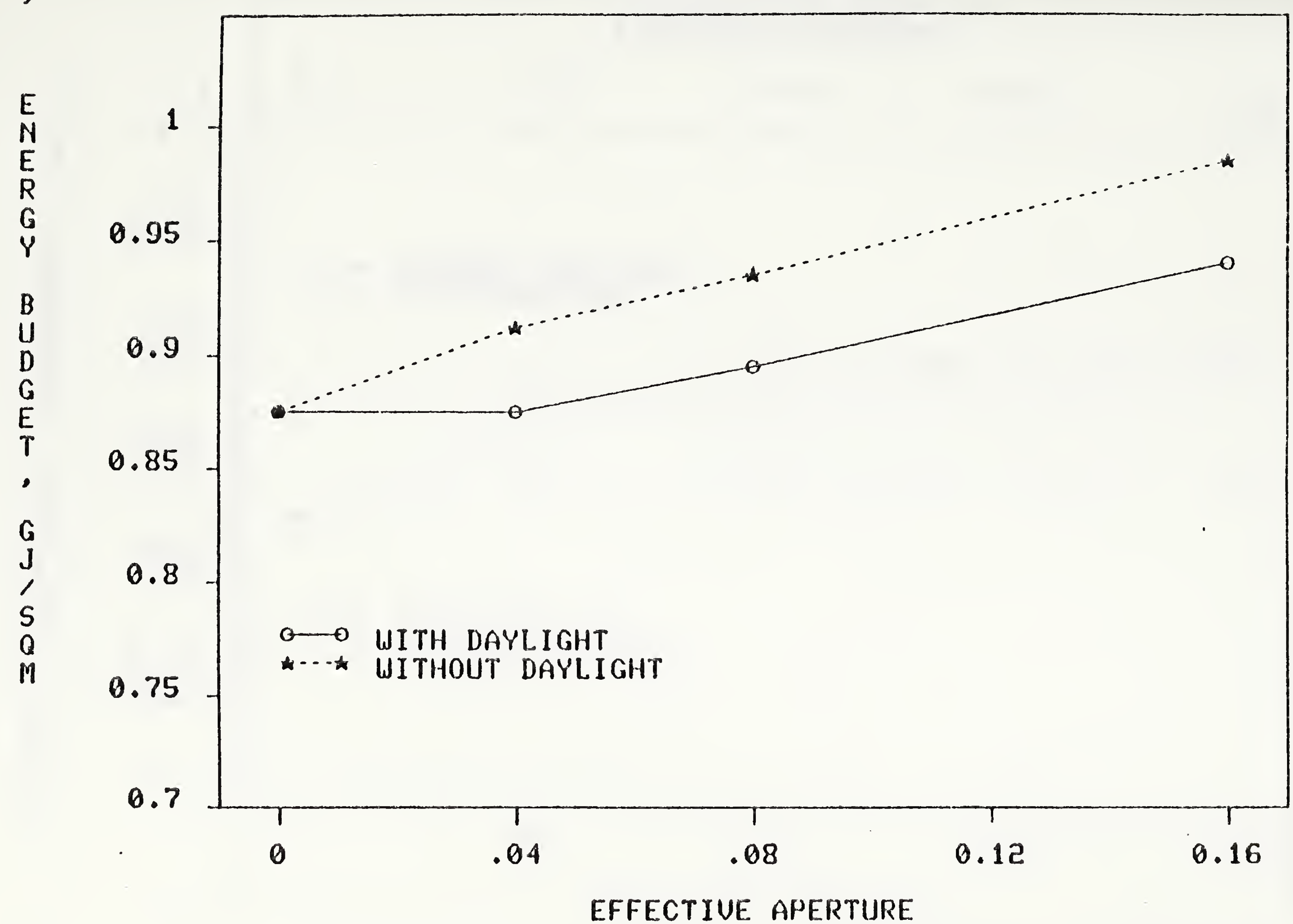


Figure 319. TOTAL ENERGY - SOUTH WINDOW (Seattle) BRICK ATTACHED

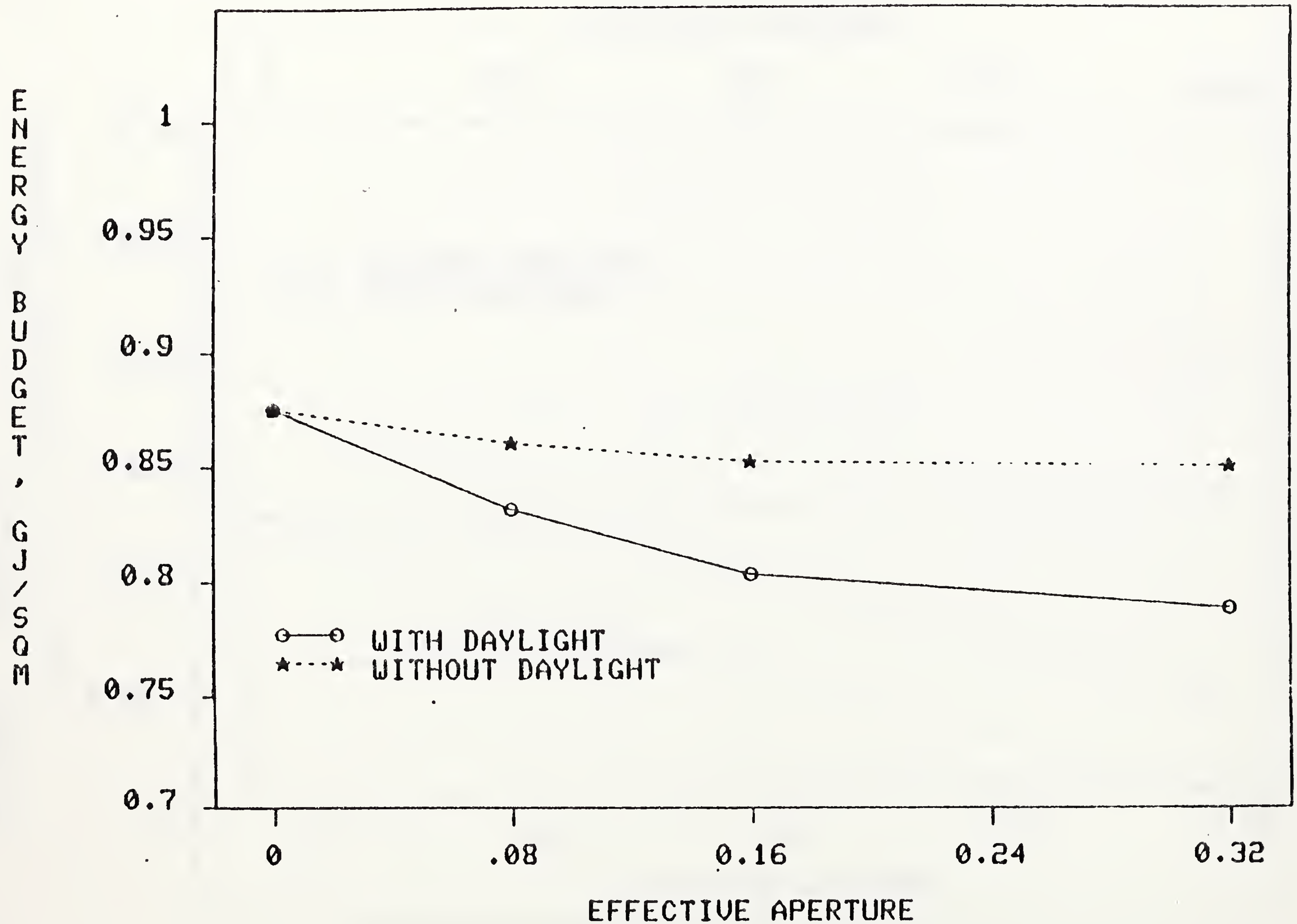


Figure 320. TOTAL ENERGY - NORTH WINDOW (Seattle)
BRICK ATTACHED

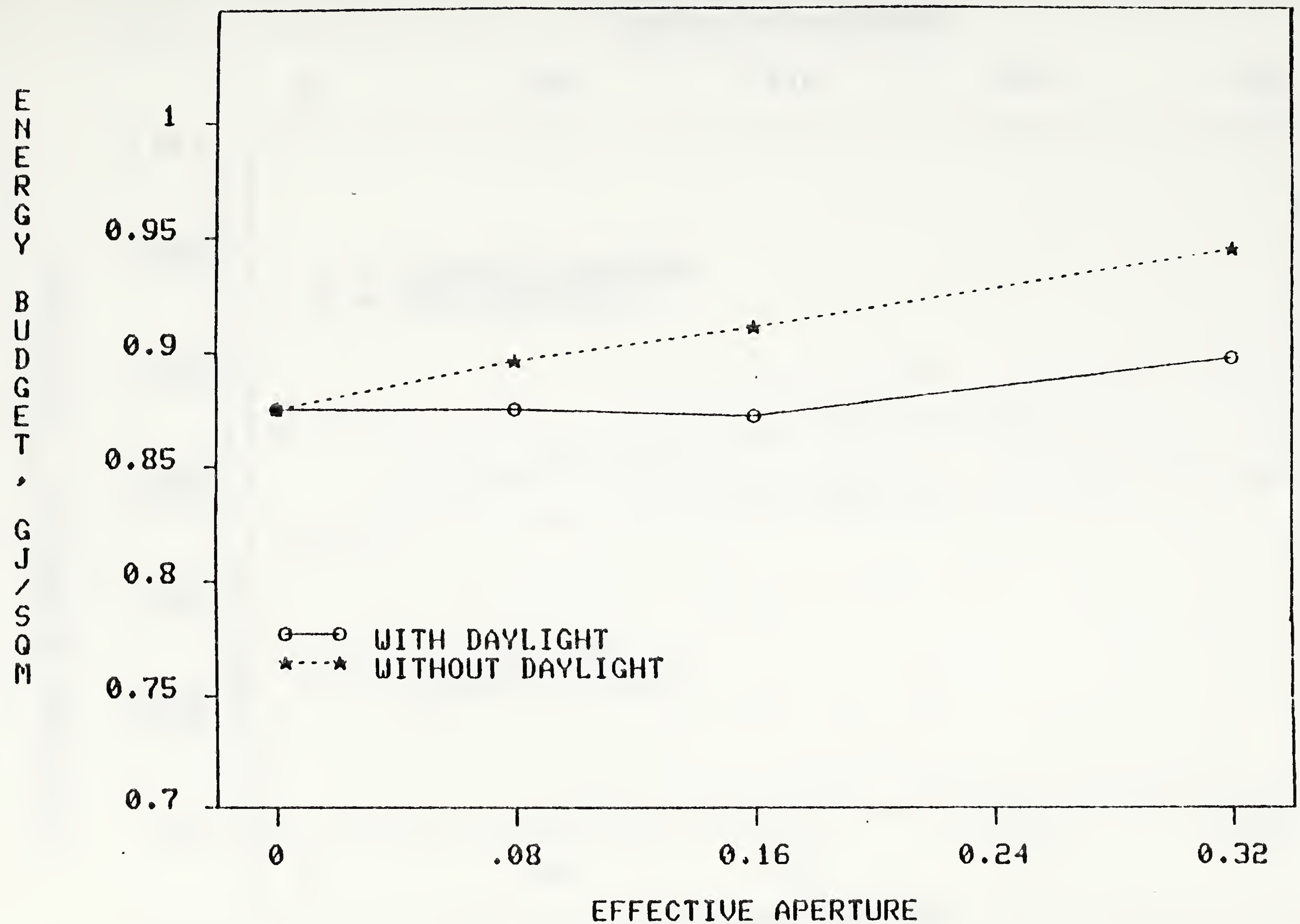


Figure 321. TOTAL ENERGY - SKYLIGHTS (Seattle)
METAL FREESTANDING

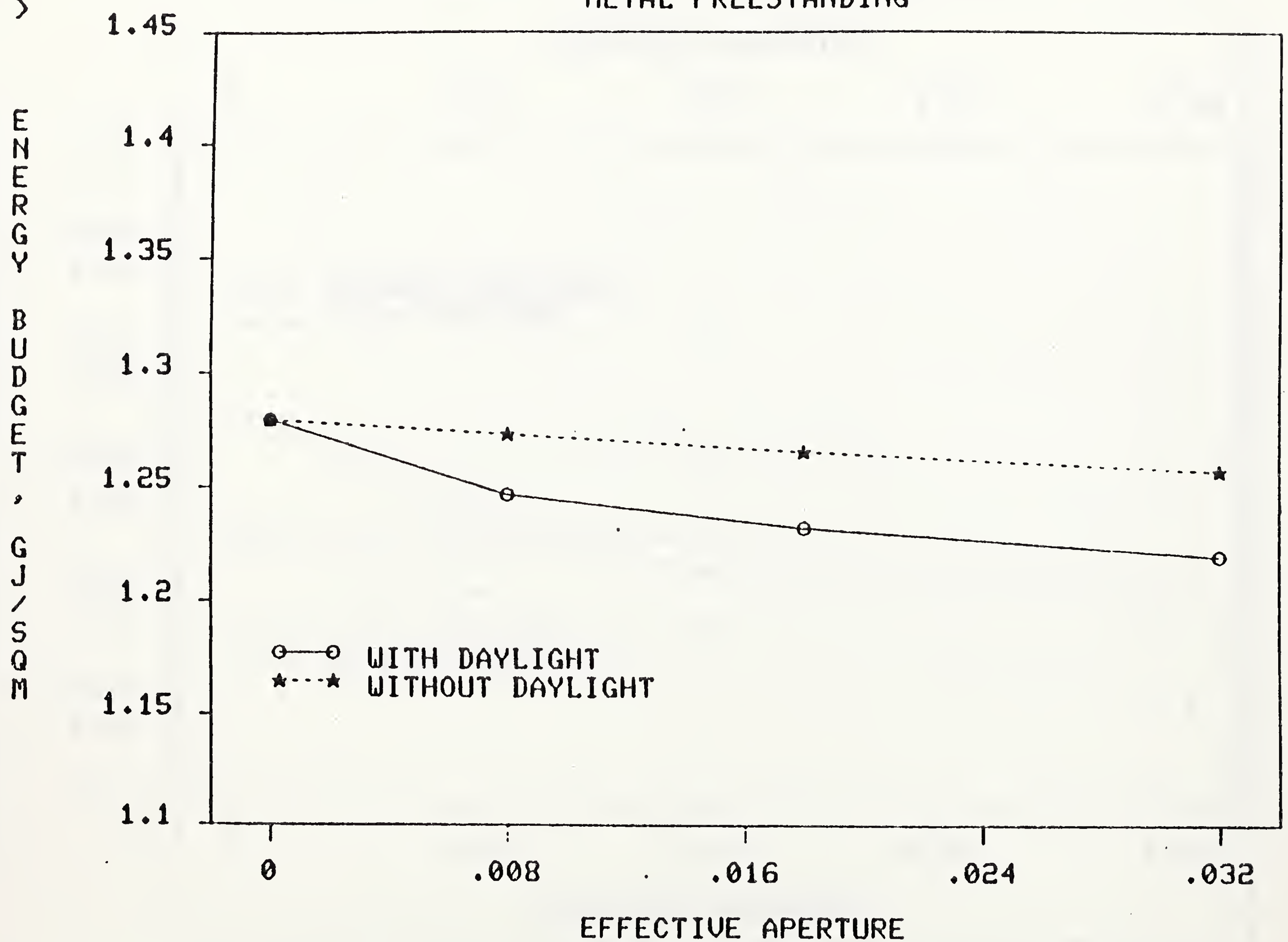


Figure 322. TOTAL ENERGY - SOUTH SAWTOOTH (Seattle)
METAL FREESTANDING

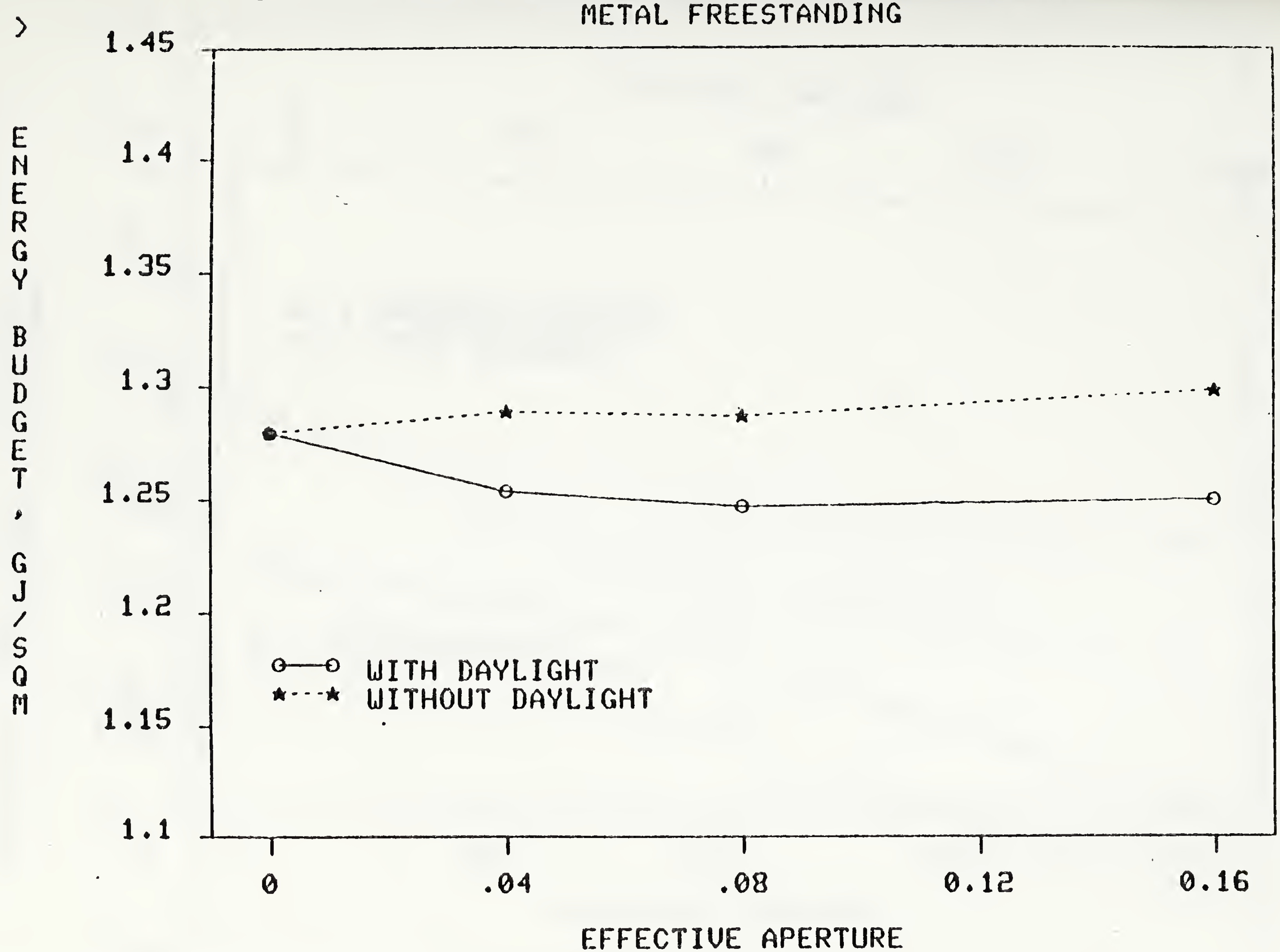


Figure 323. TOTAL ENERGY - NORTH SAWTOOTH (Seattle)
METAL FREESTANDING

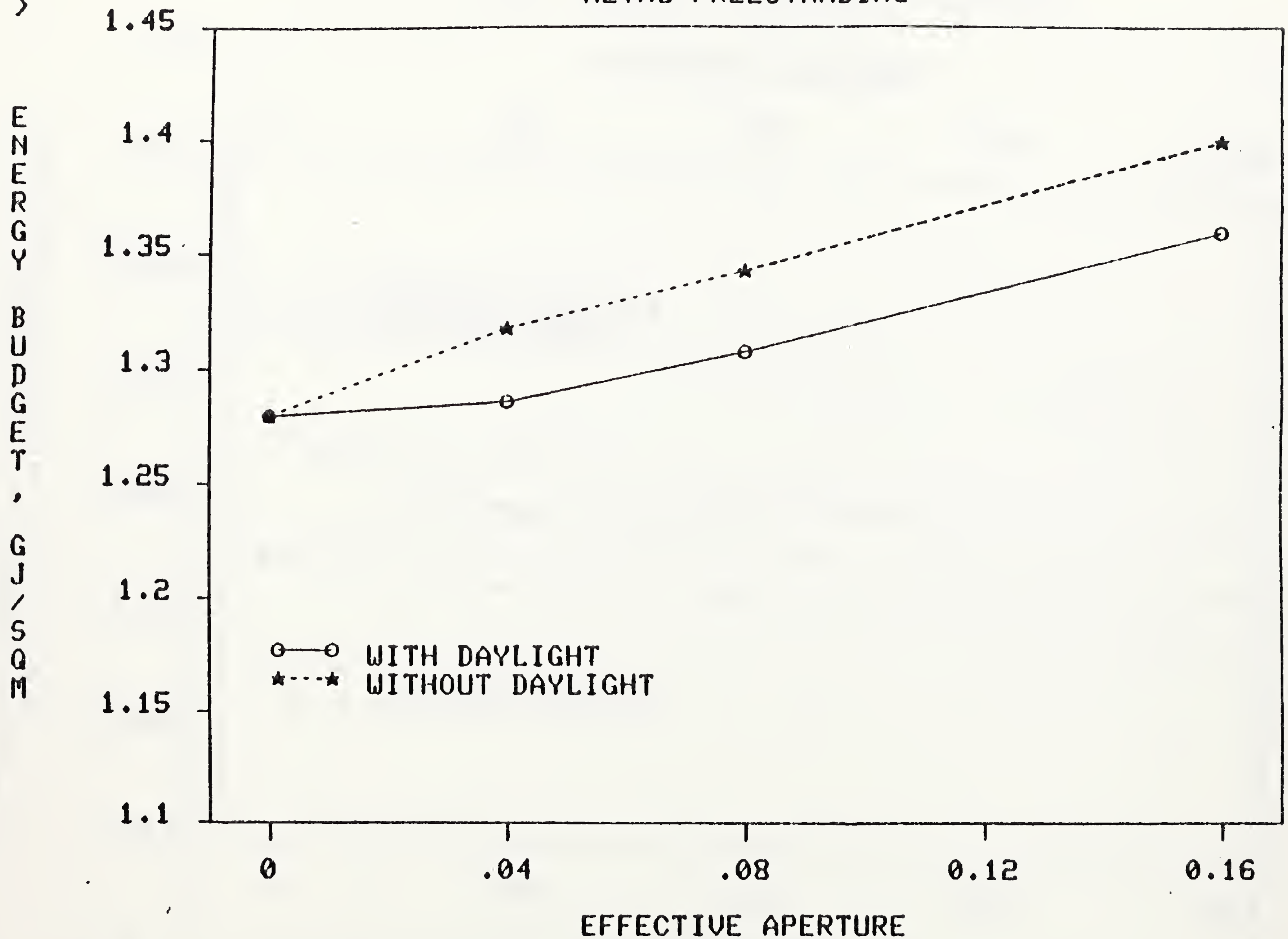


Figure 324. TOTAL ENERGY - SOUTH WINDOW (Seattle)
METAL FREESTANDING

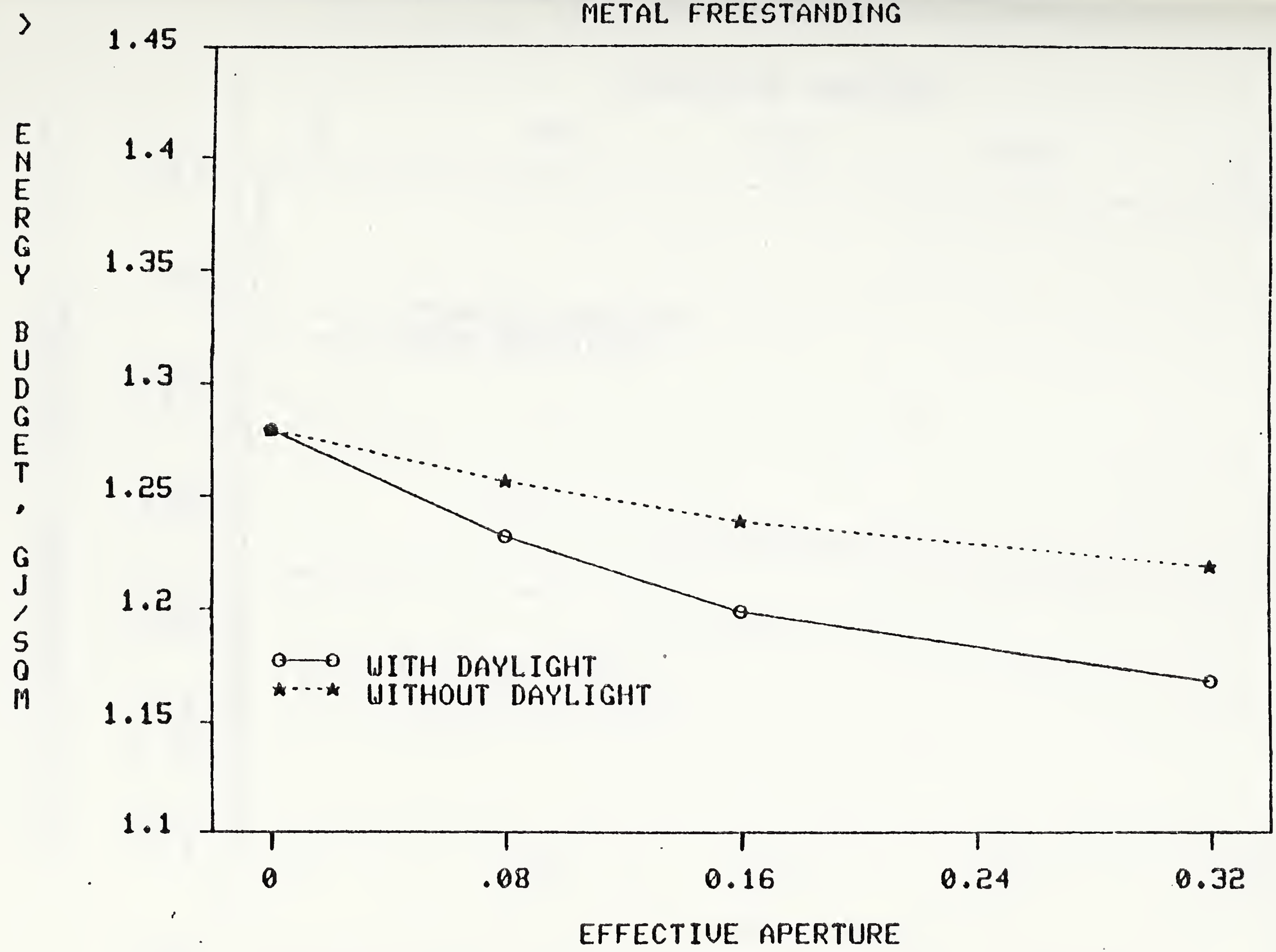


Figure 325. TOTAL ENERGY - NORTH WINDOW (Seattle)
METAL FREESTANDING

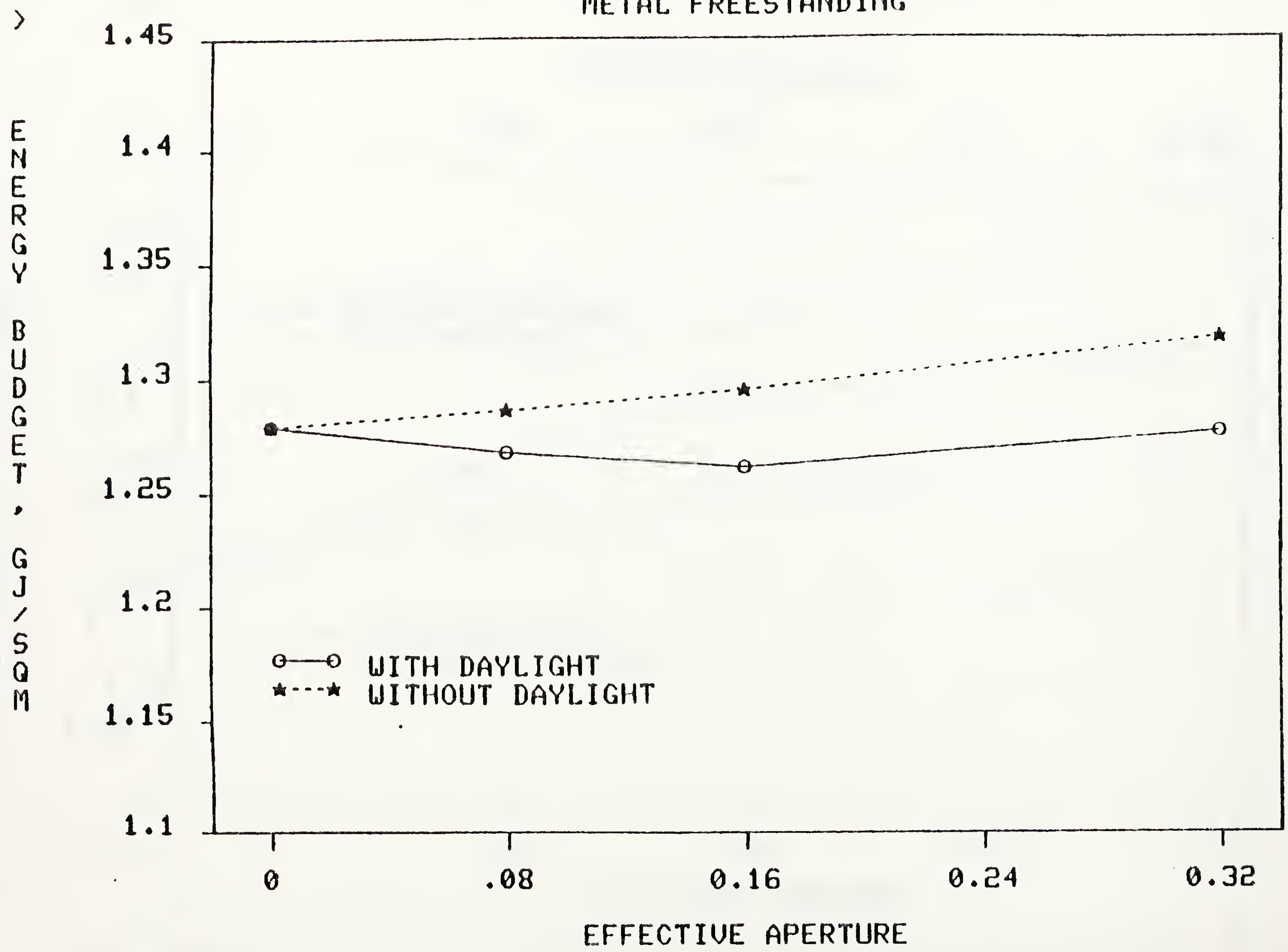


Figure 326. TOTAL ENERGY - SKYLIGHTS (Seattle)
METAL ATTACHED

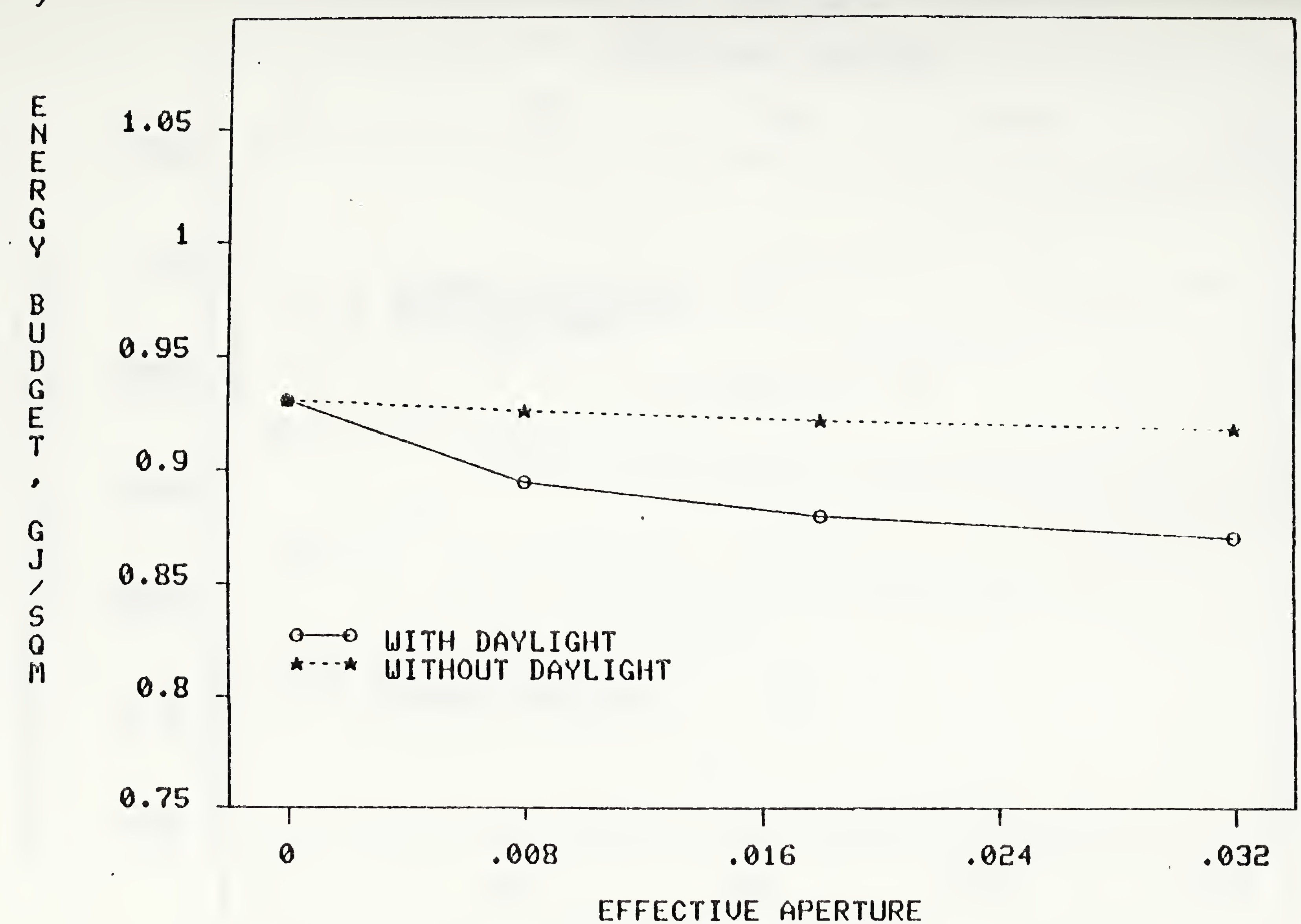


Figure 327. TOTAL ENERGY - SOUTH SAWTOOTH (Seattle)
METAL ATTACHED

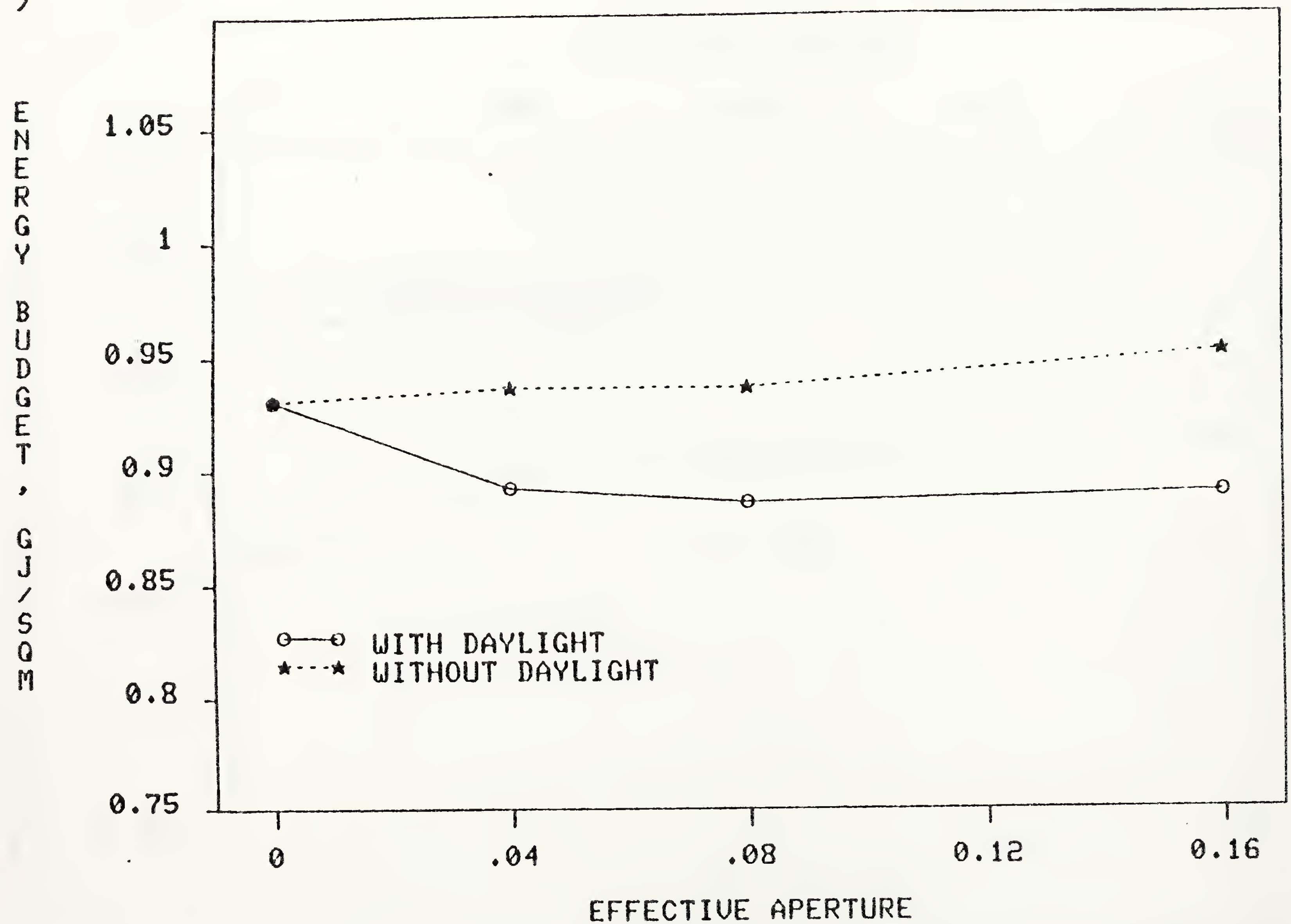


Figure 328. TOTAL ENERGY - NORTH SAWTOOTH (Seattle)
METAL ATTACHED

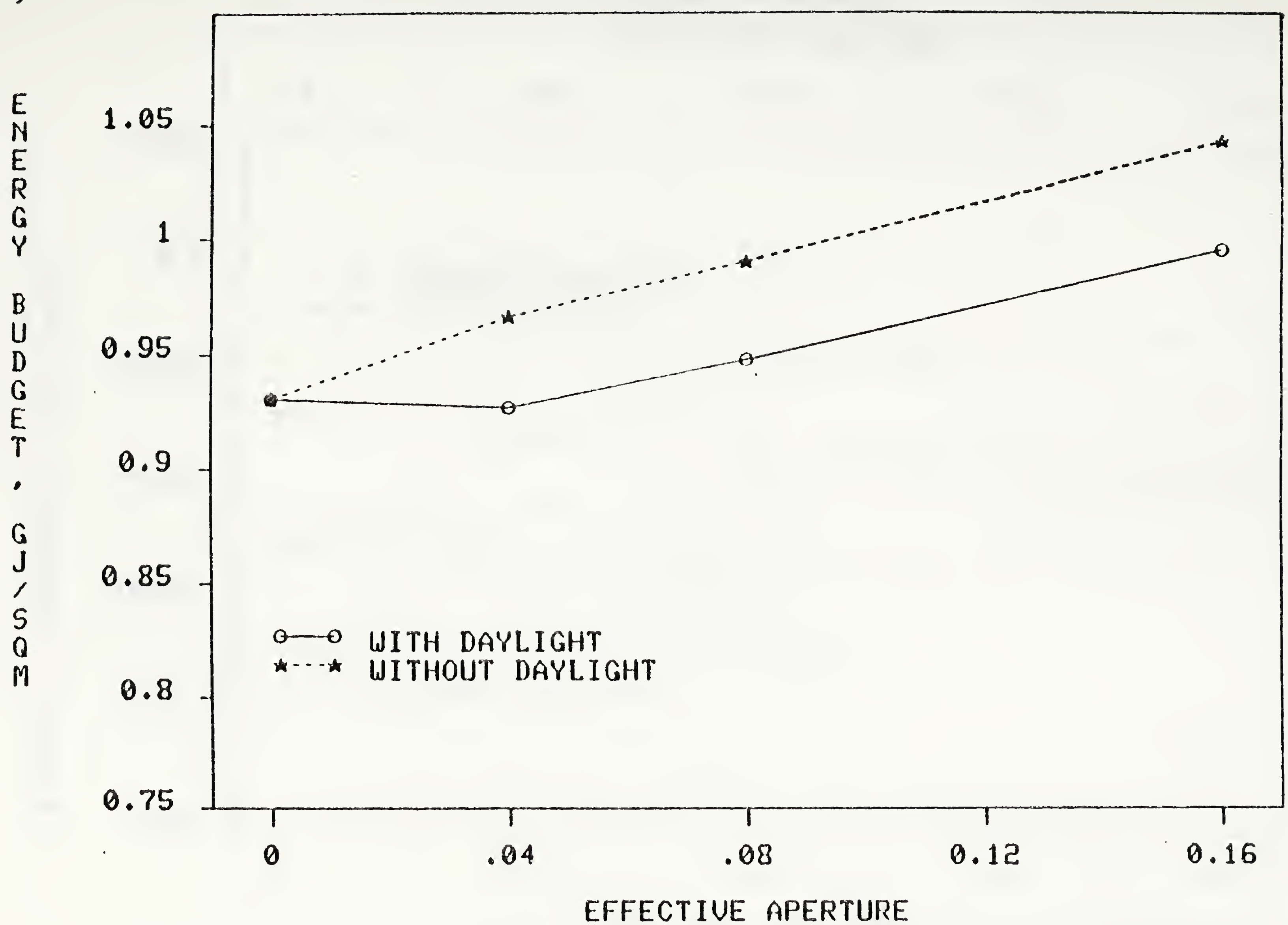


Figure 329. TOTAL ENERGY - SOUTH WINDOW (Seattle)
METAL ATTACHED

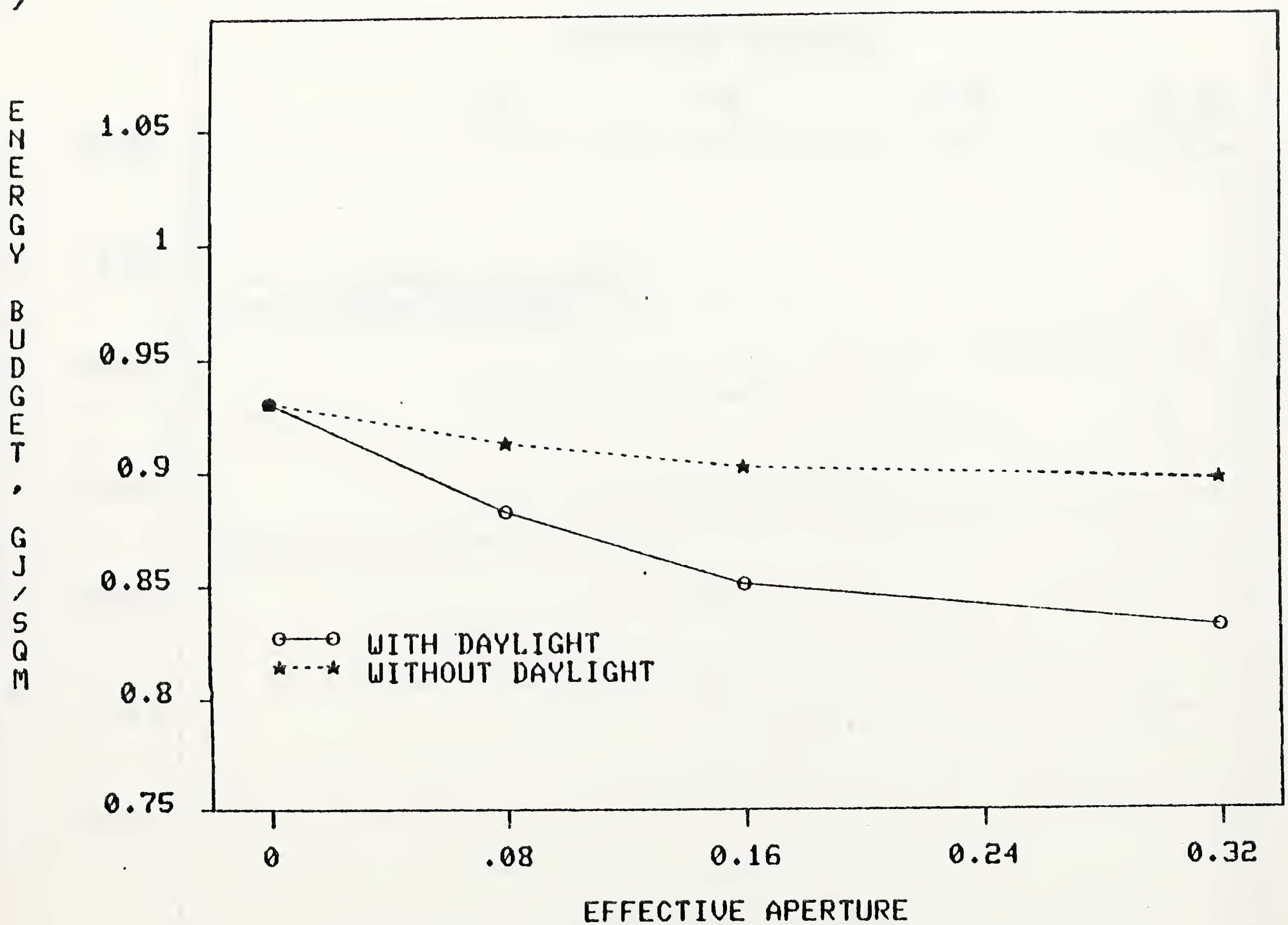


Figure 330. TOTAL ENERGY - NORTH WINDOW (Seattle)
METAL ATTACHED

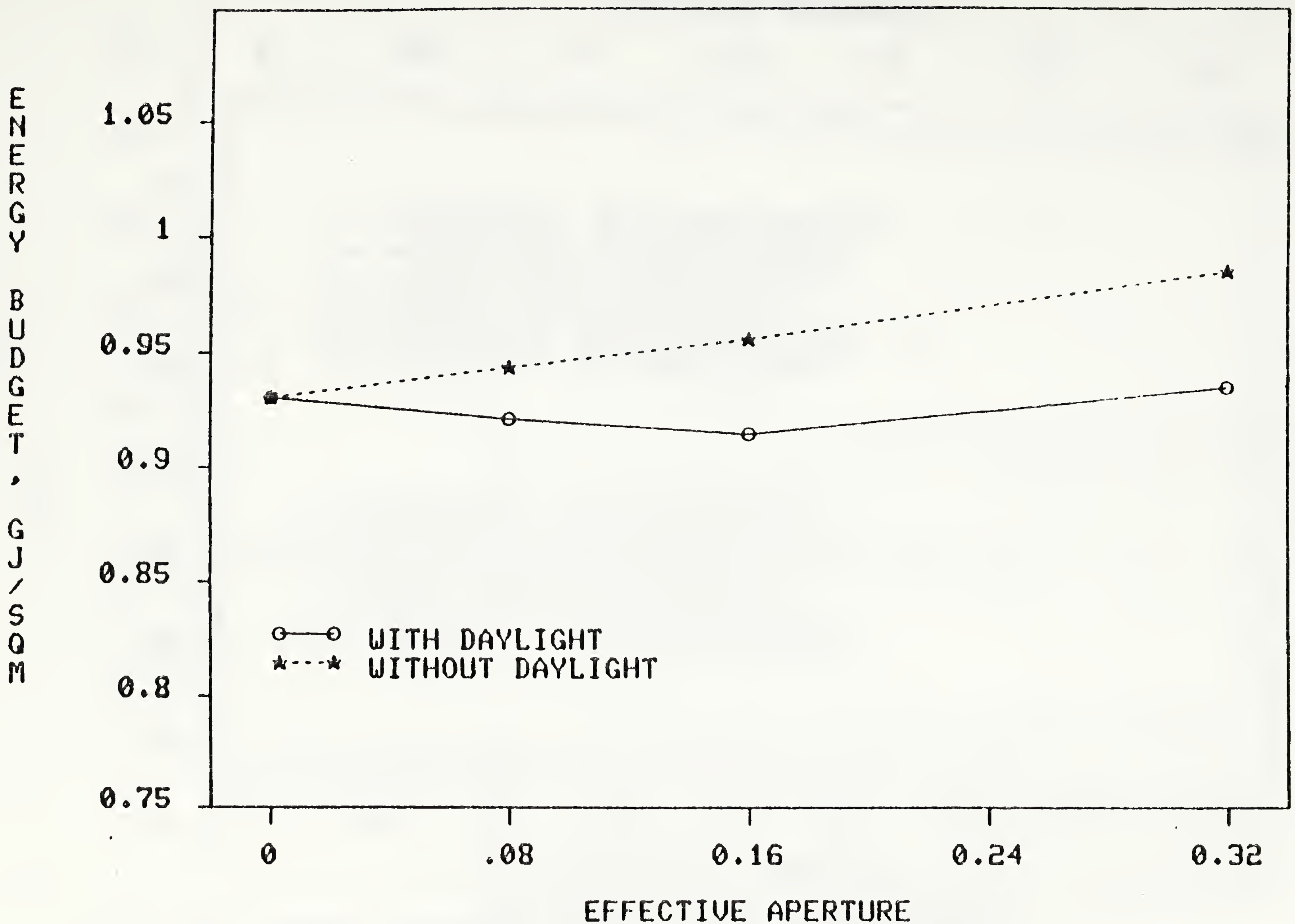


Figure 331. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
SKYLIGHTS, BRICK FREESTANDING

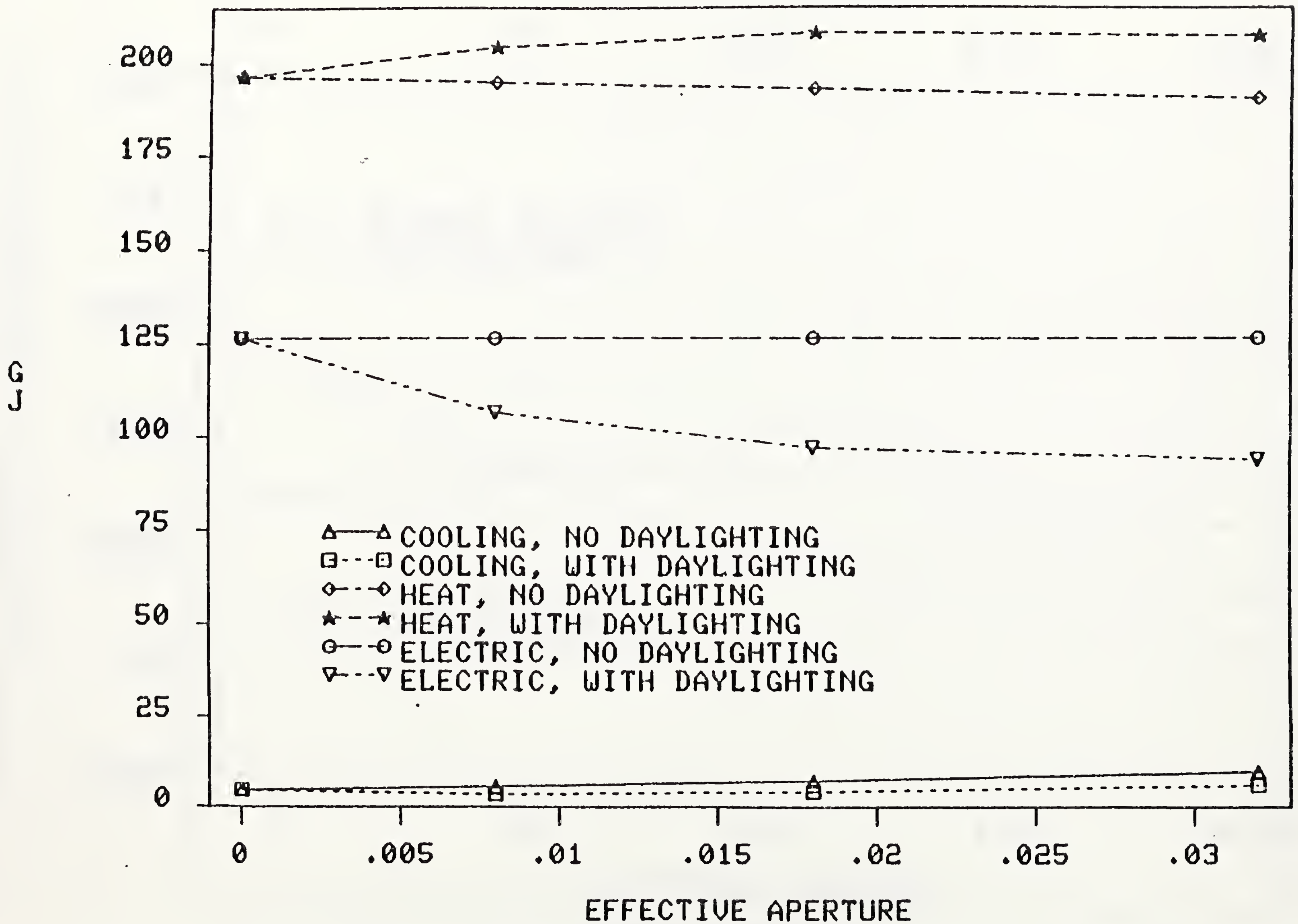


Figure 332. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
SOUTH SAWTOOTH, BRICK FREESTANDING

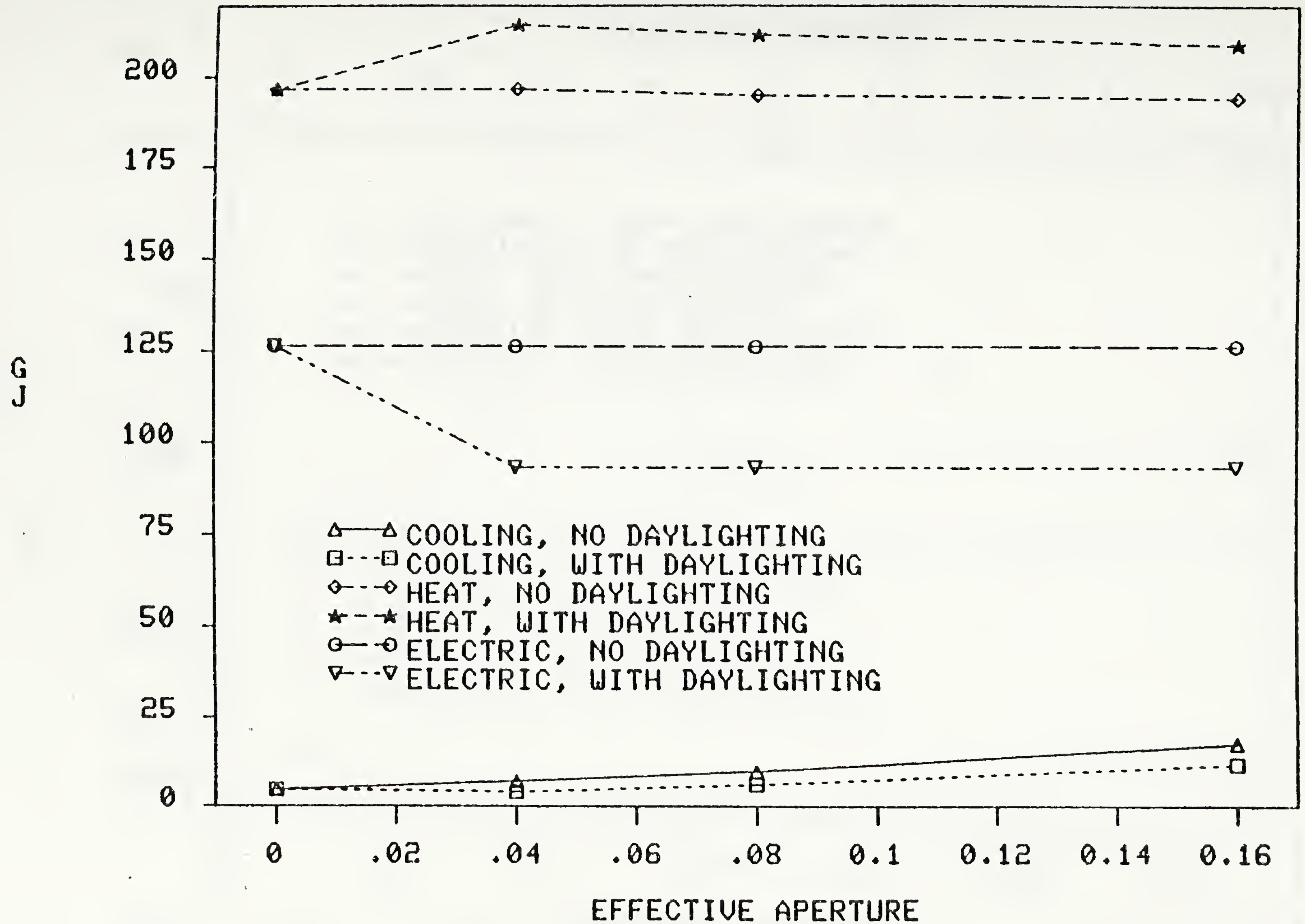


Figure 333. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle) NORTH SAWTOOTH, BRICK FREESTANDING

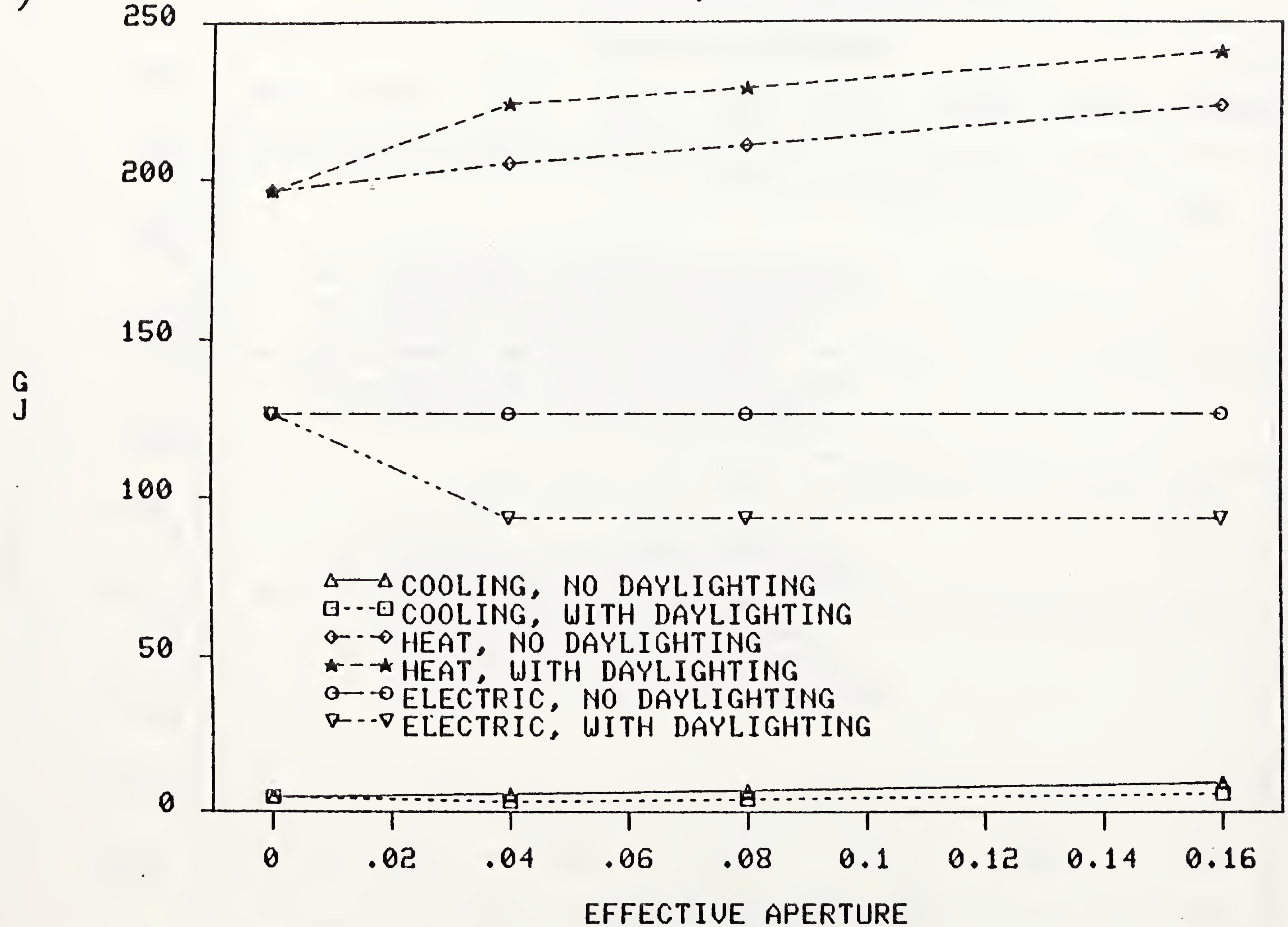


Figure 334. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle) SOUTH WINDOW, BRICK FREESTANDING

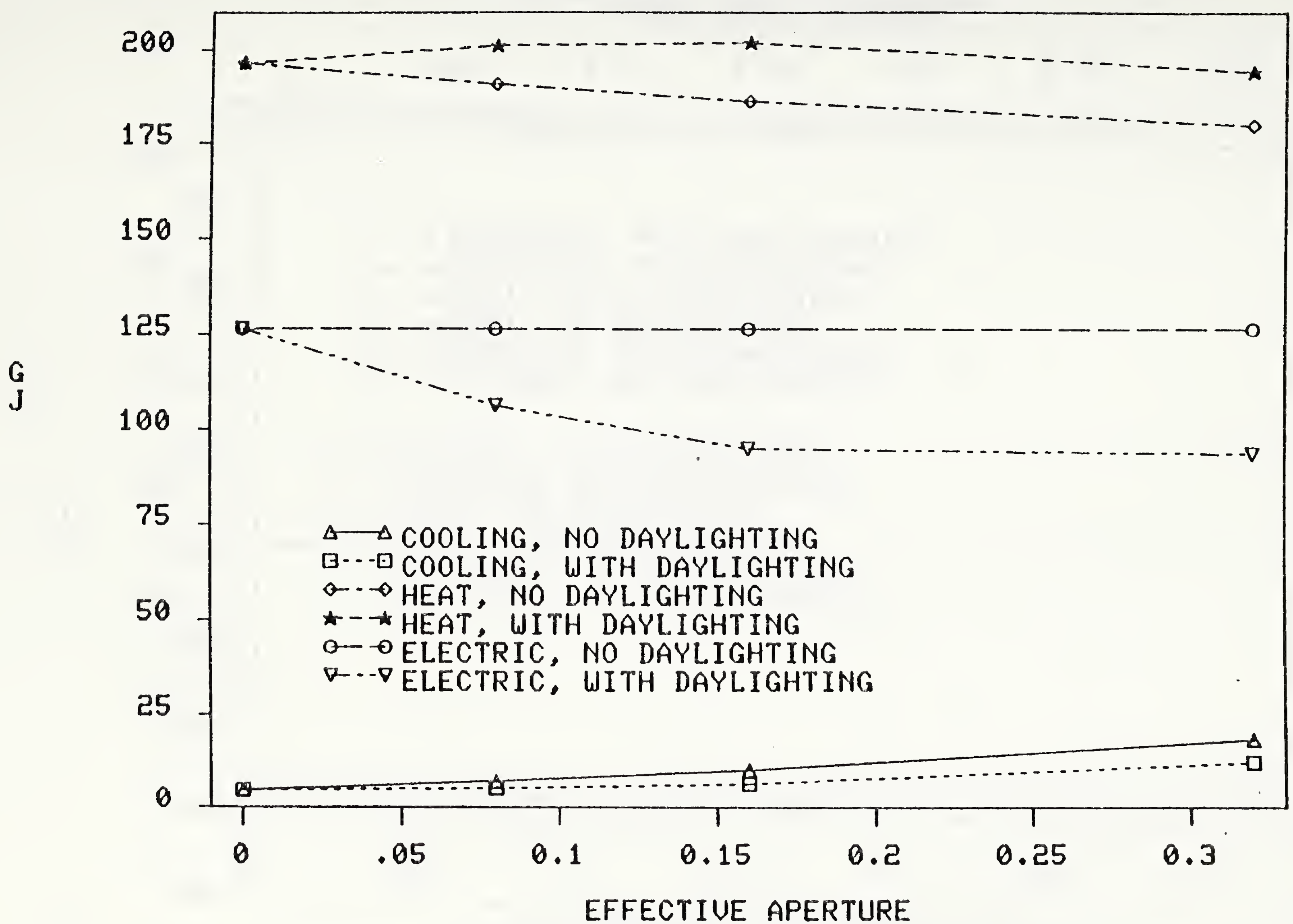


Figure 335. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
NORTH WINDOW, BRICK FREESTANDING

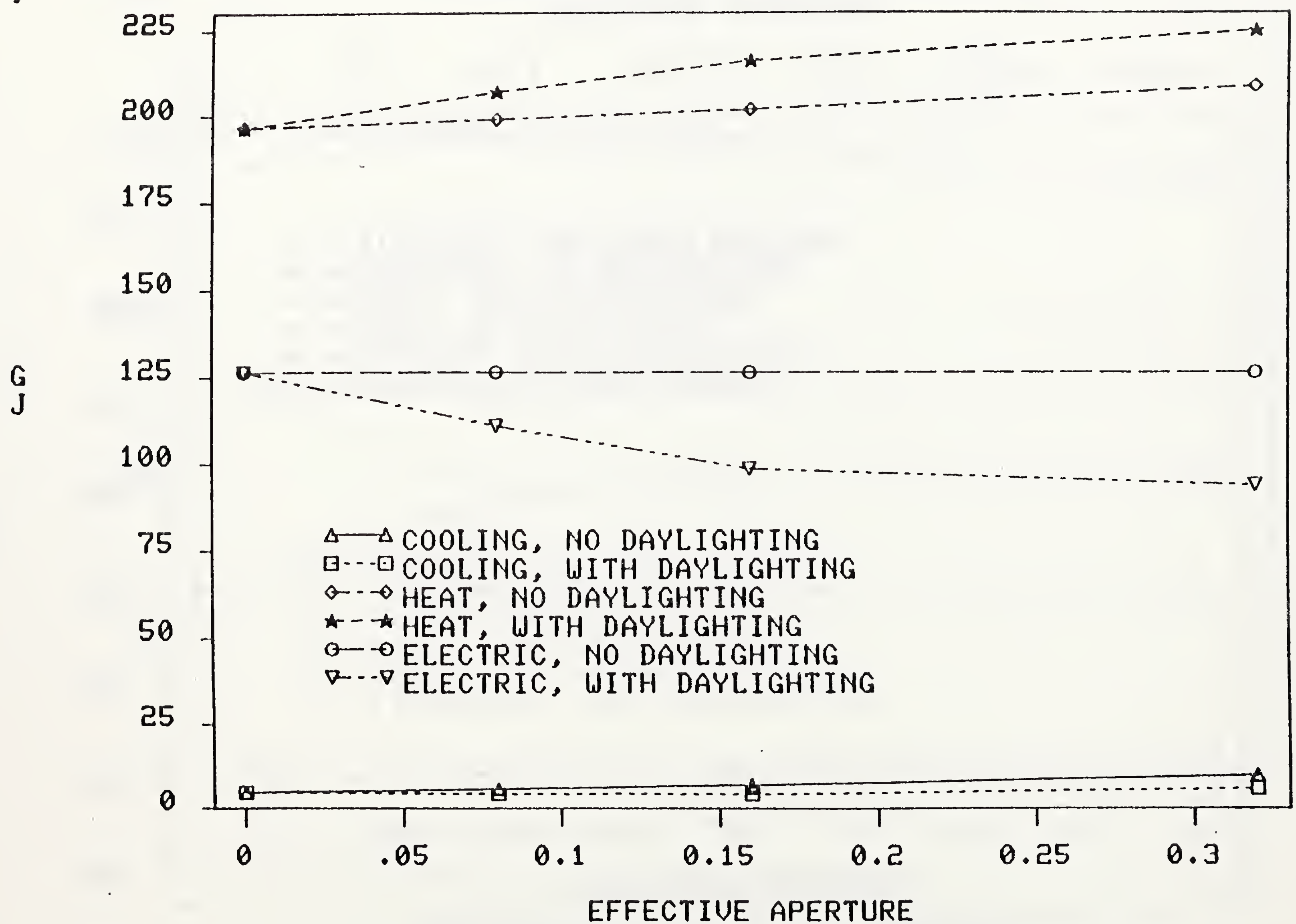


Figure 336. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
SKYLIGHTS, BRICK ATTACHED

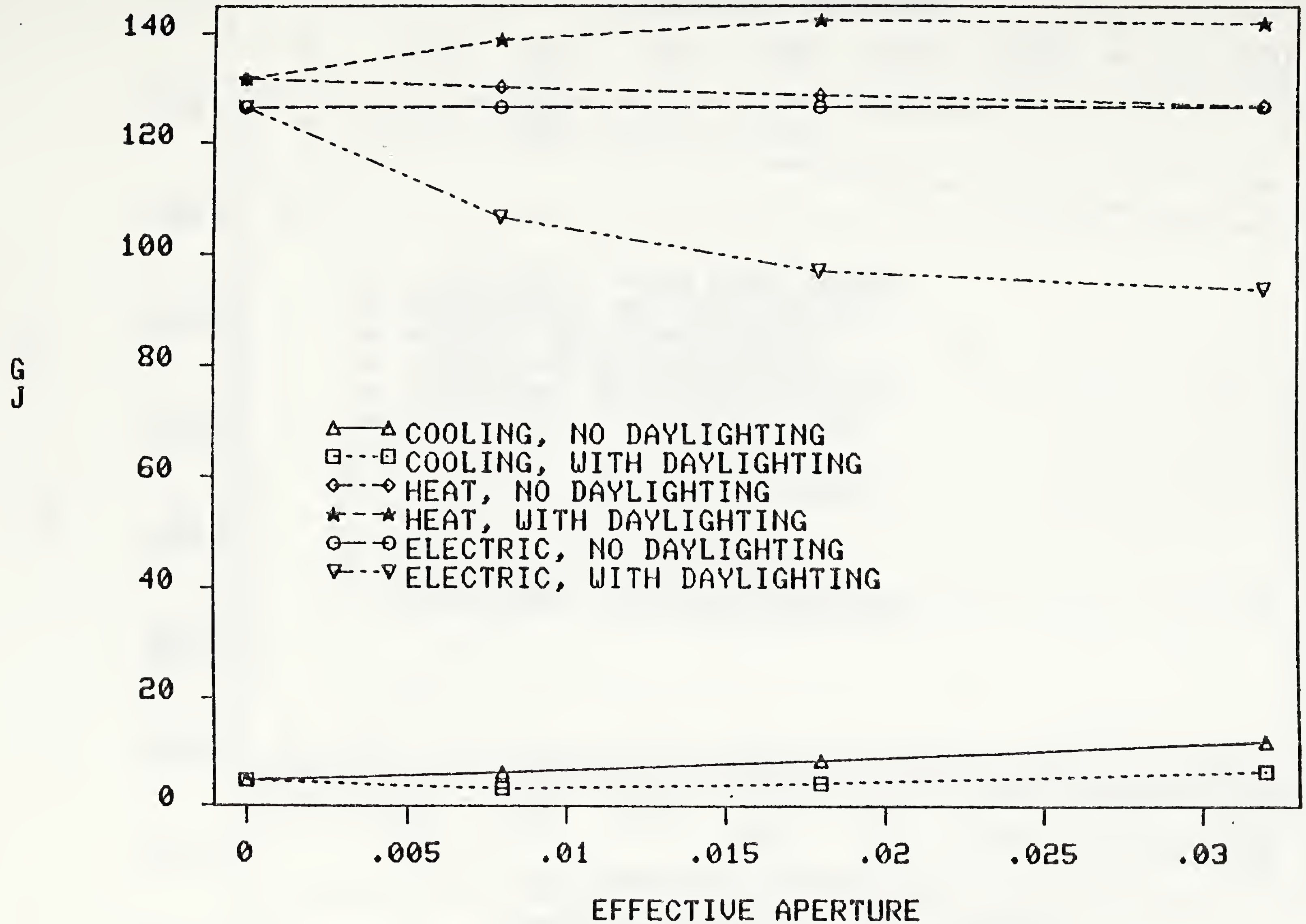


Figure 337. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
SOUTH SAWTOOTH, BRICK ATTACHED

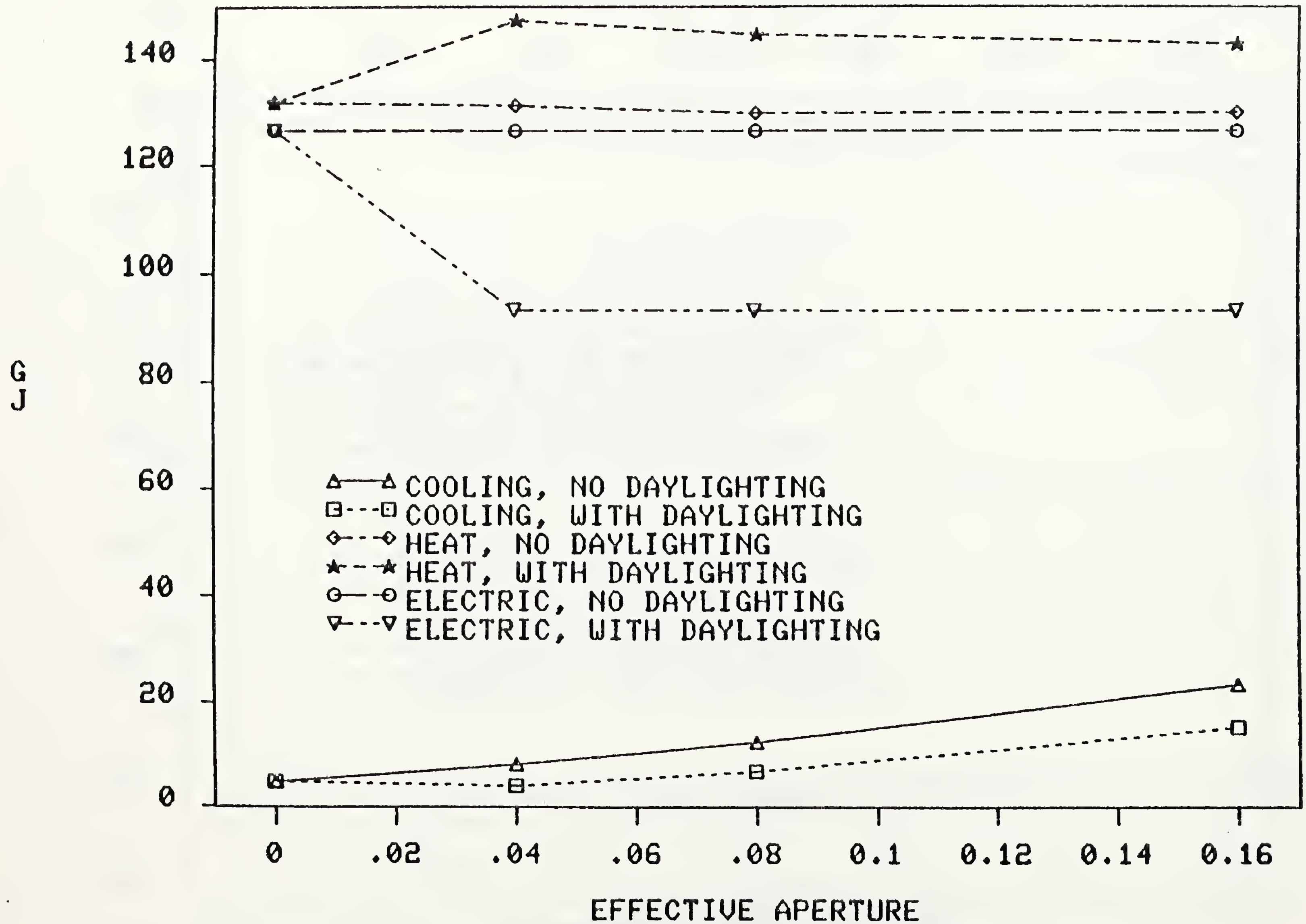


Figure 338. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
NORTH SAWTOOTH, BRICK ATTACHED

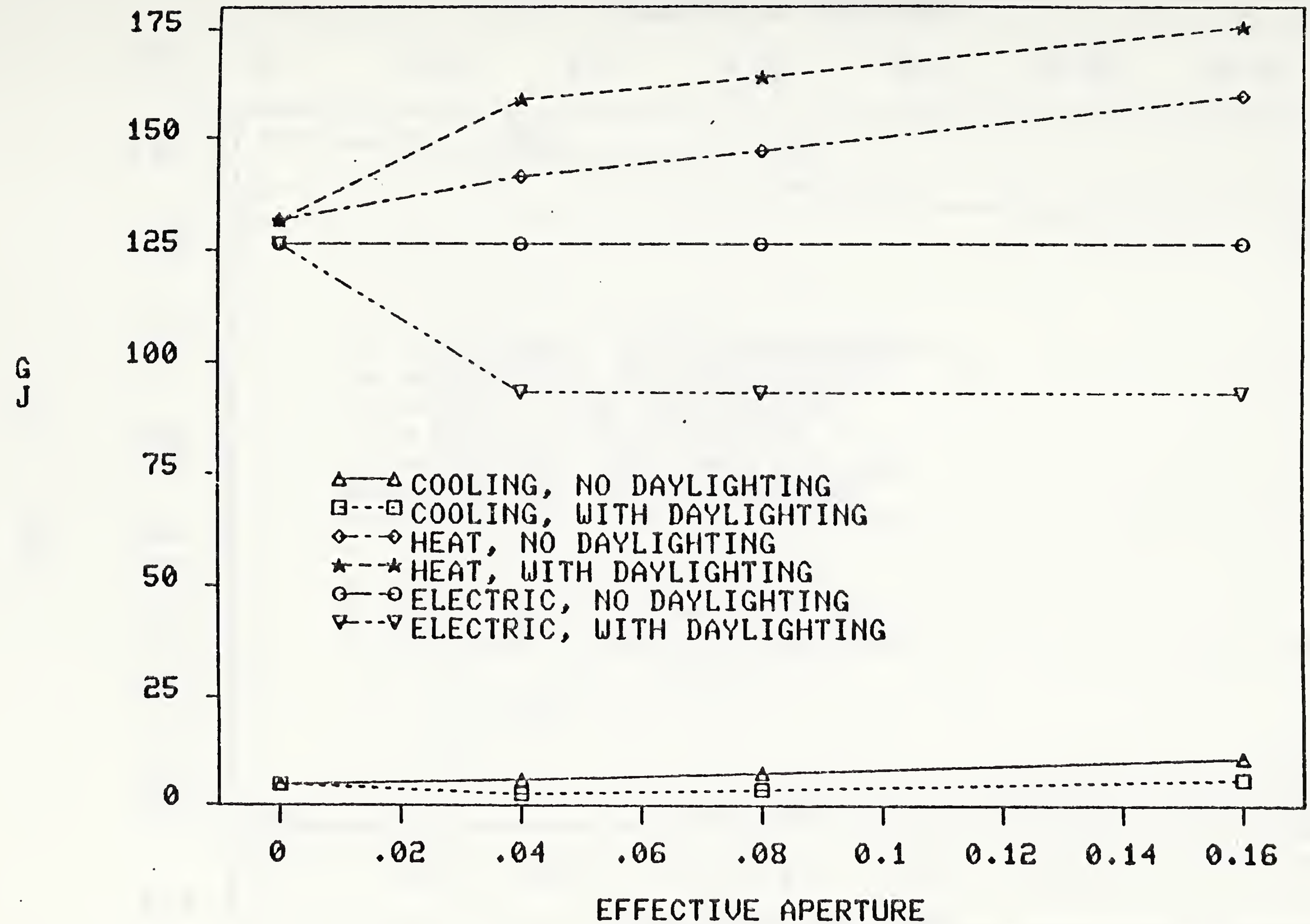


Figure 339. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
SOUTH WINDOW, BRICK ATTACHED

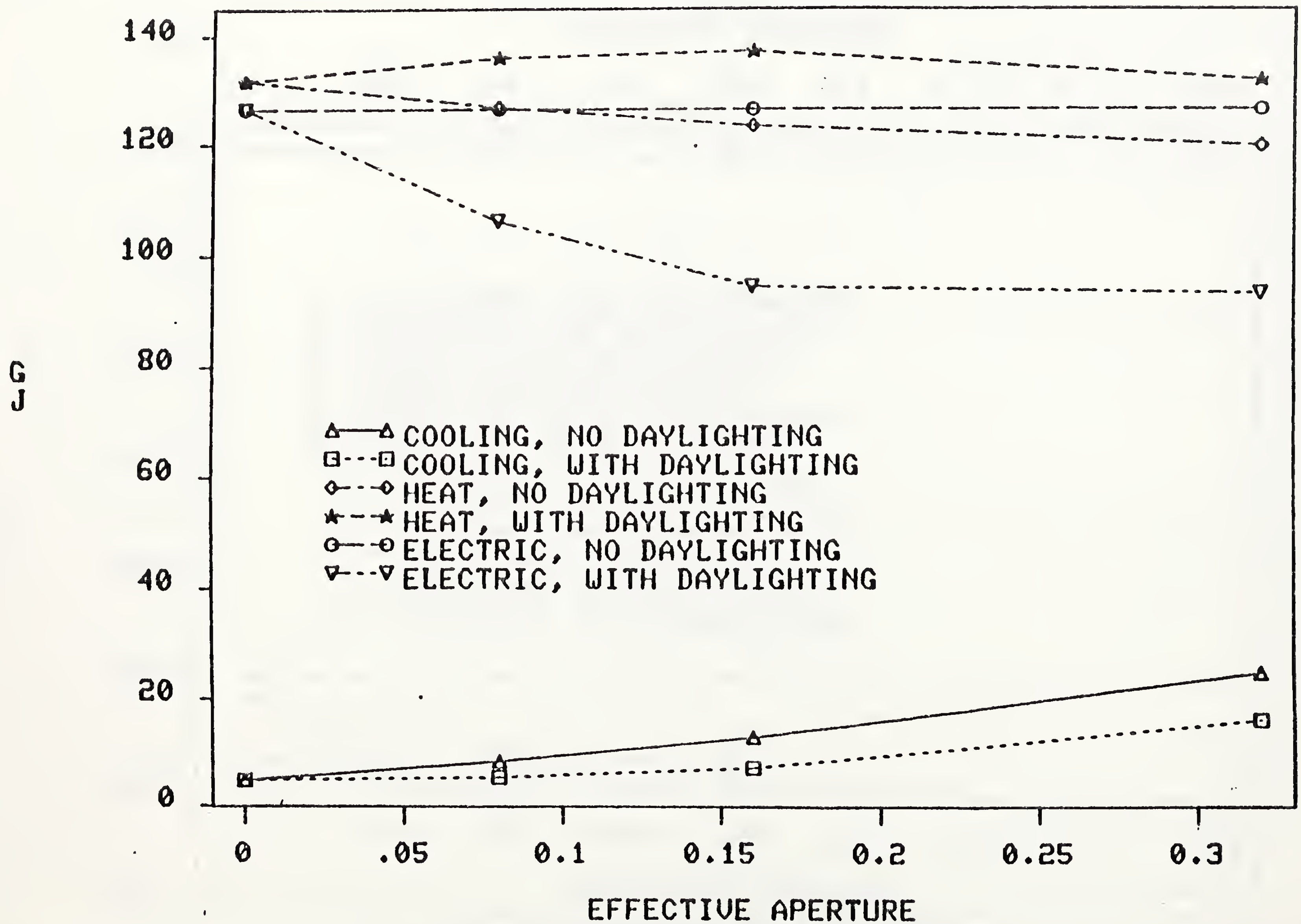


Figure 340. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
NORTH WINDOW, BRICK ATTACHED

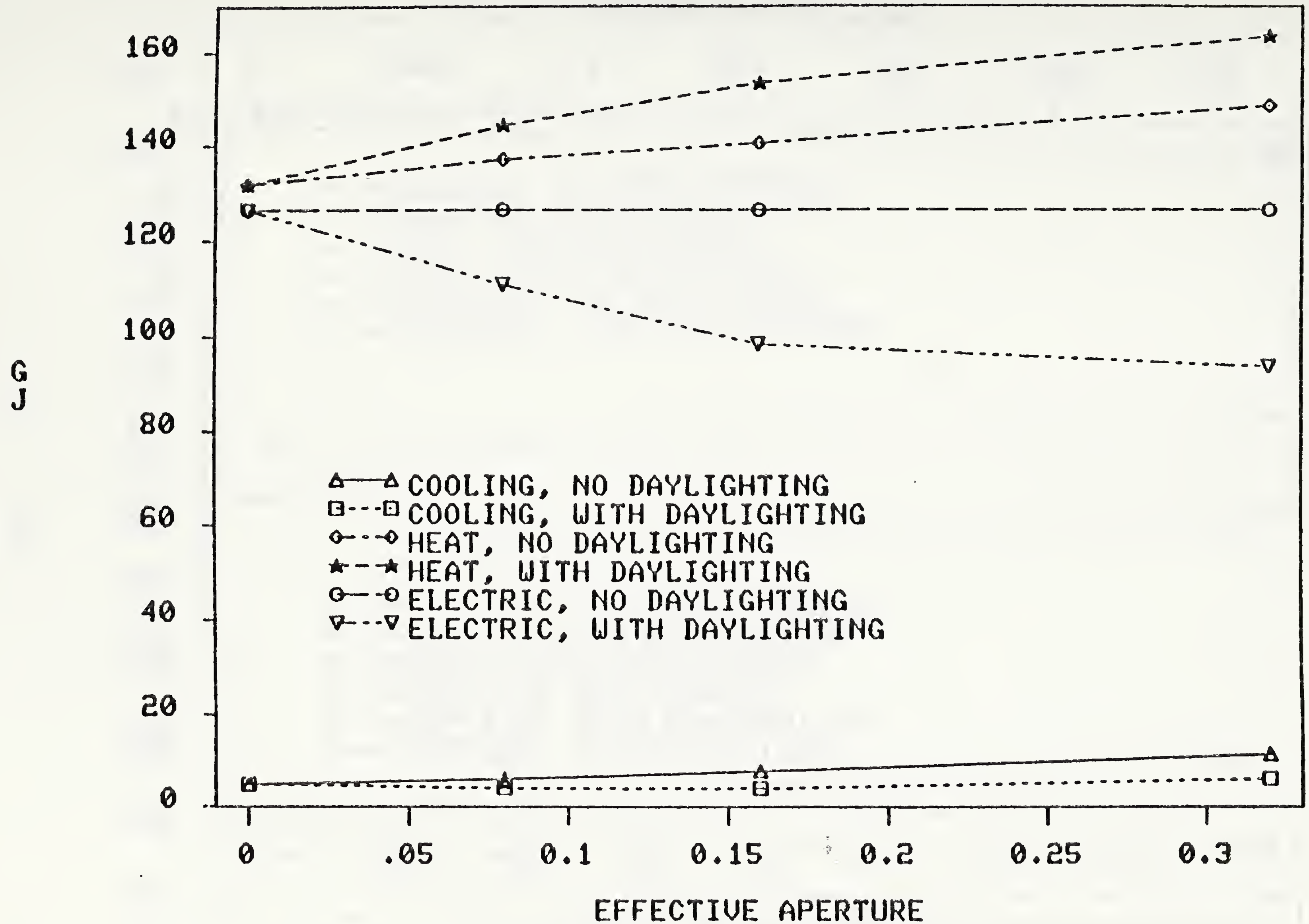


Figure 341. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle) SKYLIGHTS, METAL FREESTANDING

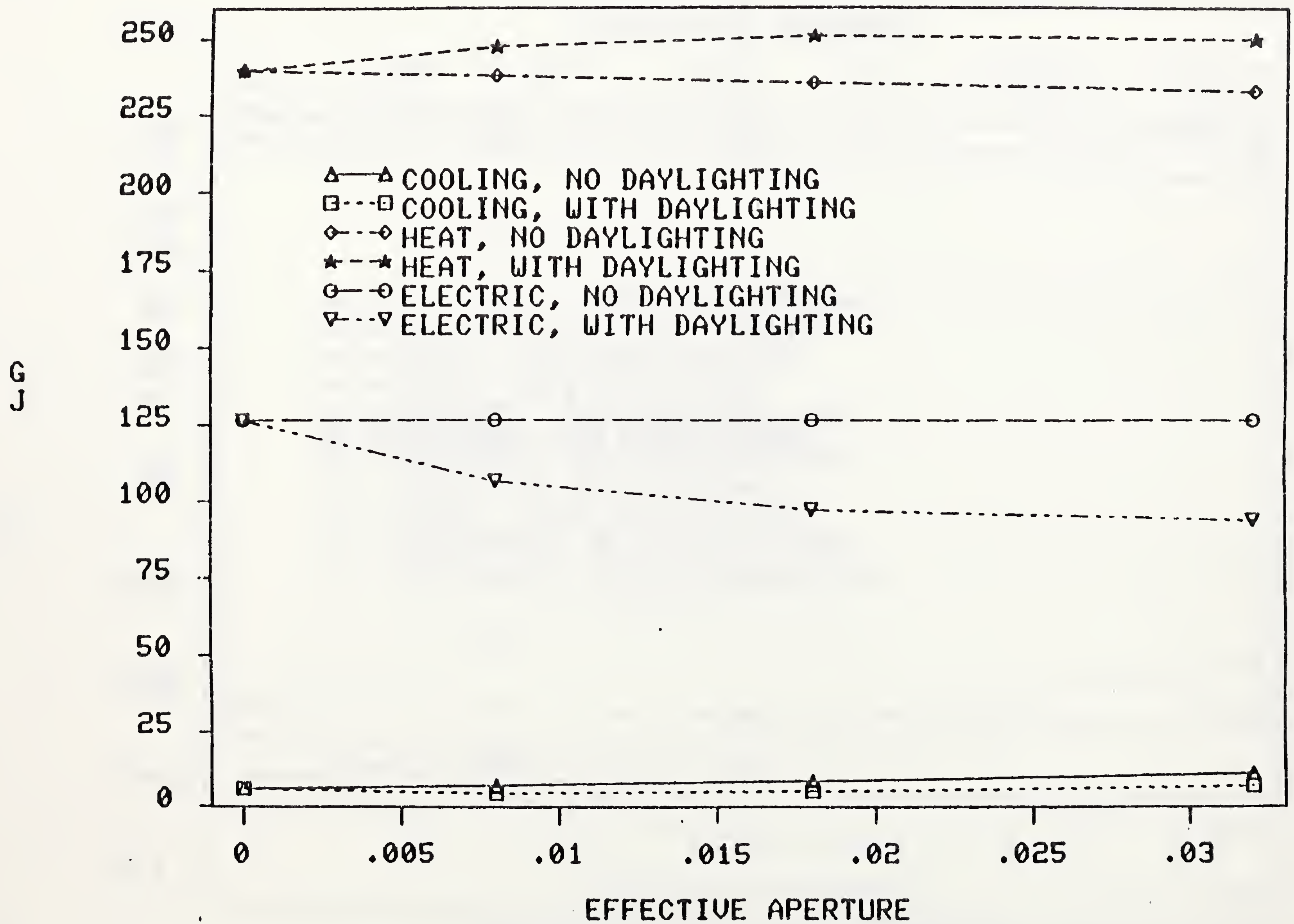


Figure 342. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
SOUTH SAWTOOTH, METAL FREESTANDING

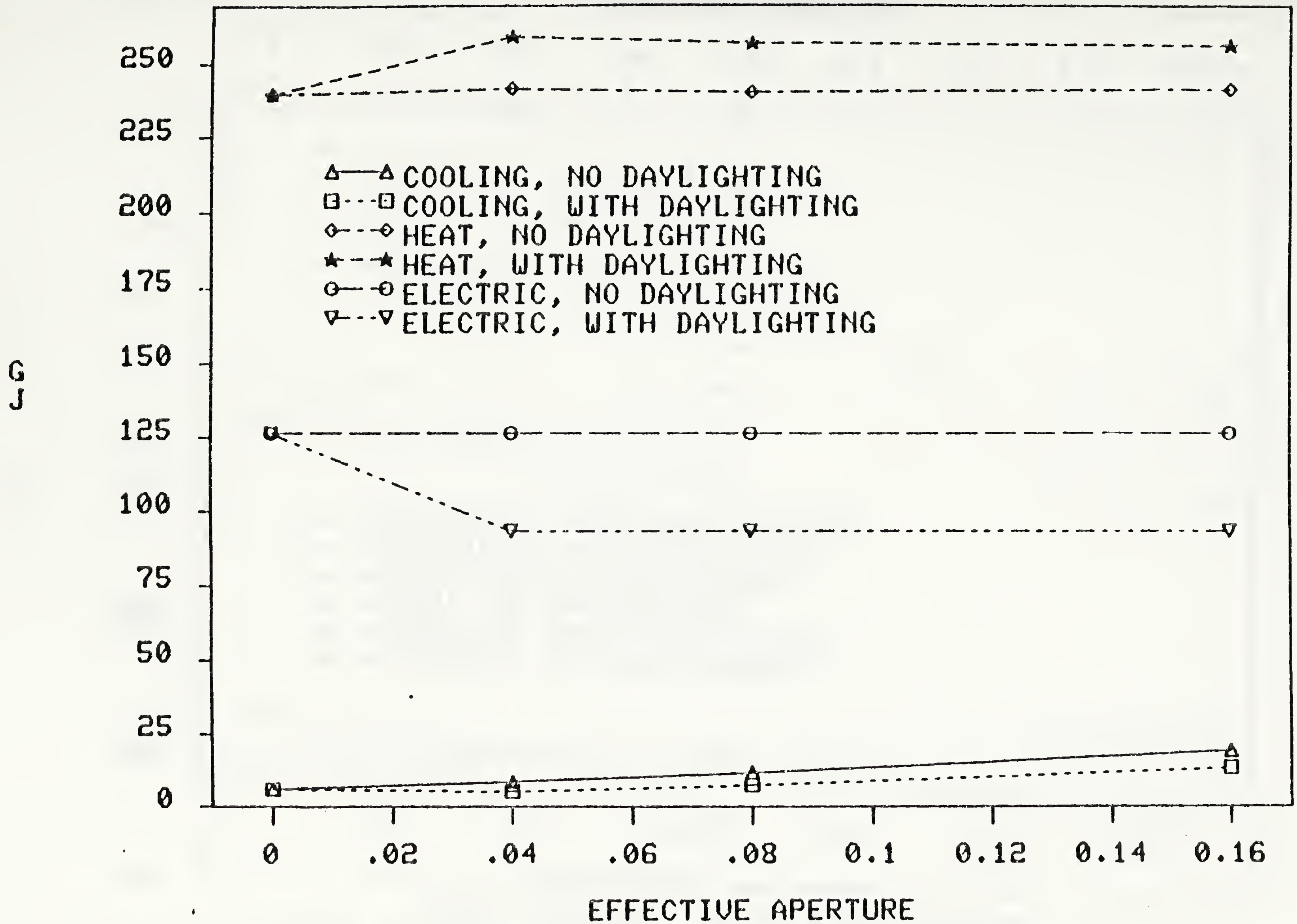


Figure 343. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
NORTH SAWTOOTH, METAL FREESTANDING

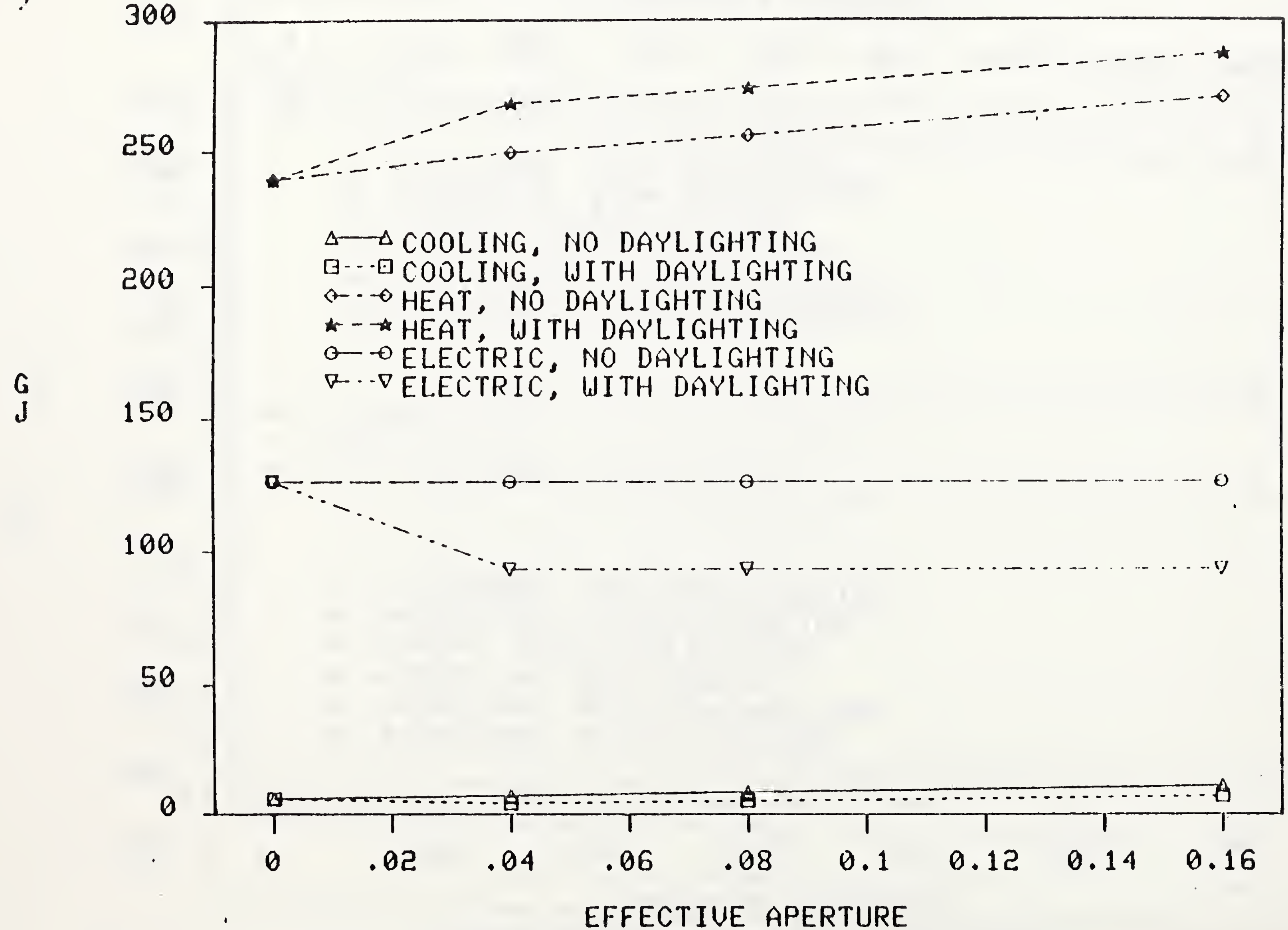


Figure 344. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle) SOUTH WINDOW, METAL FREESTANDING

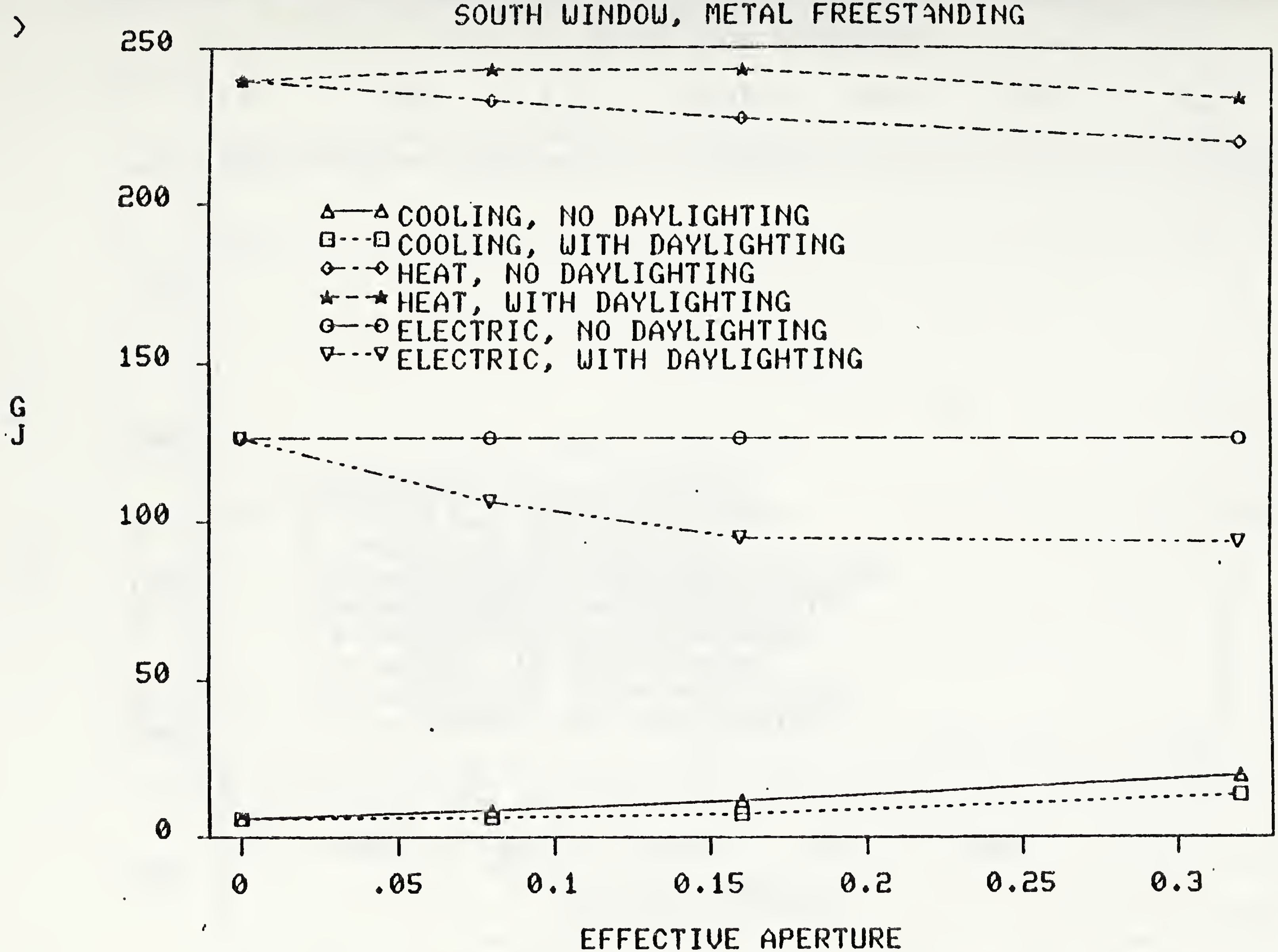


Figure 345. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
NORTH WINDOW, METAL FREESTANDING

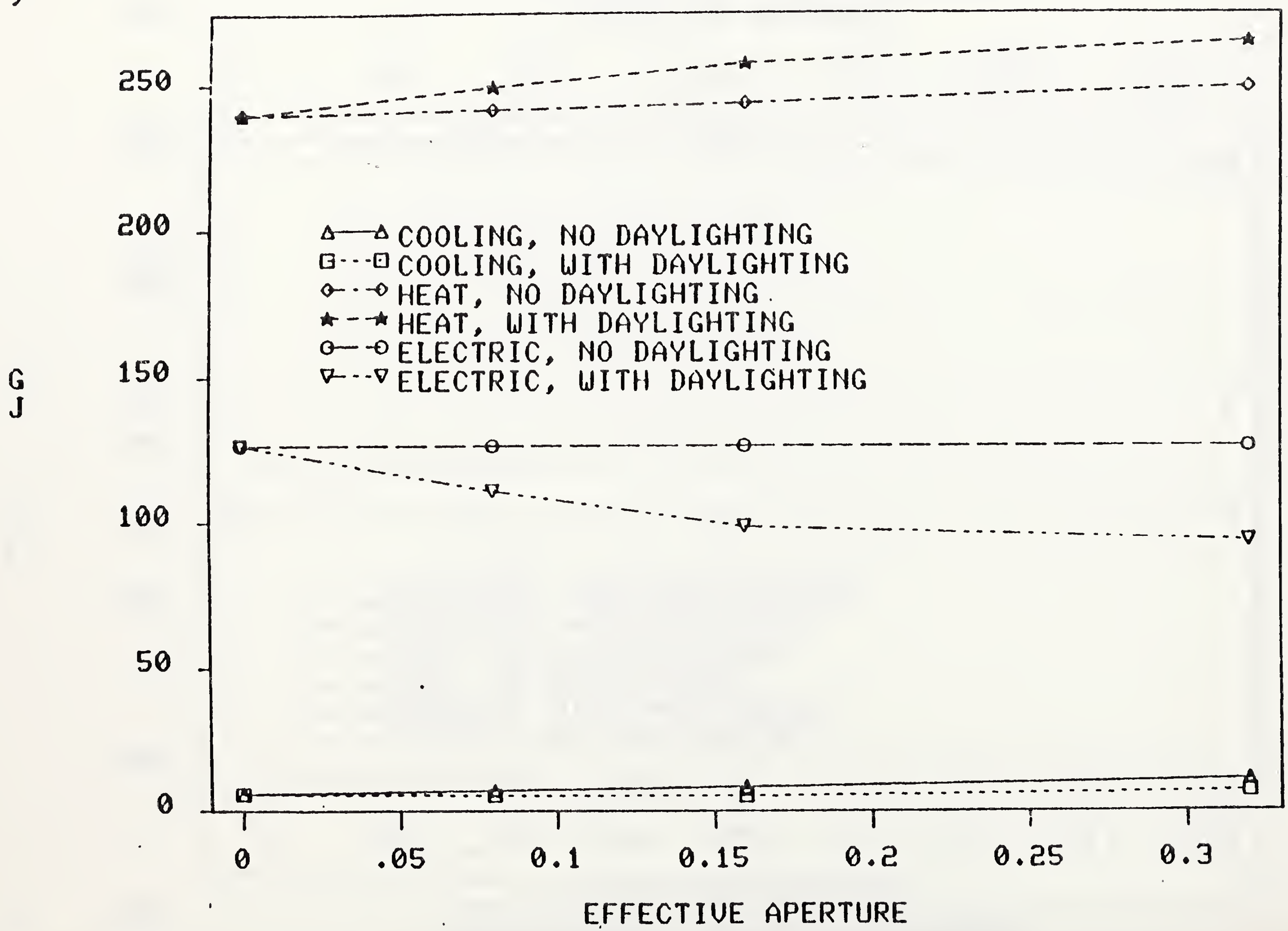


Figure 3.46. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
SKYLIGHTS, METAL ATTACHED

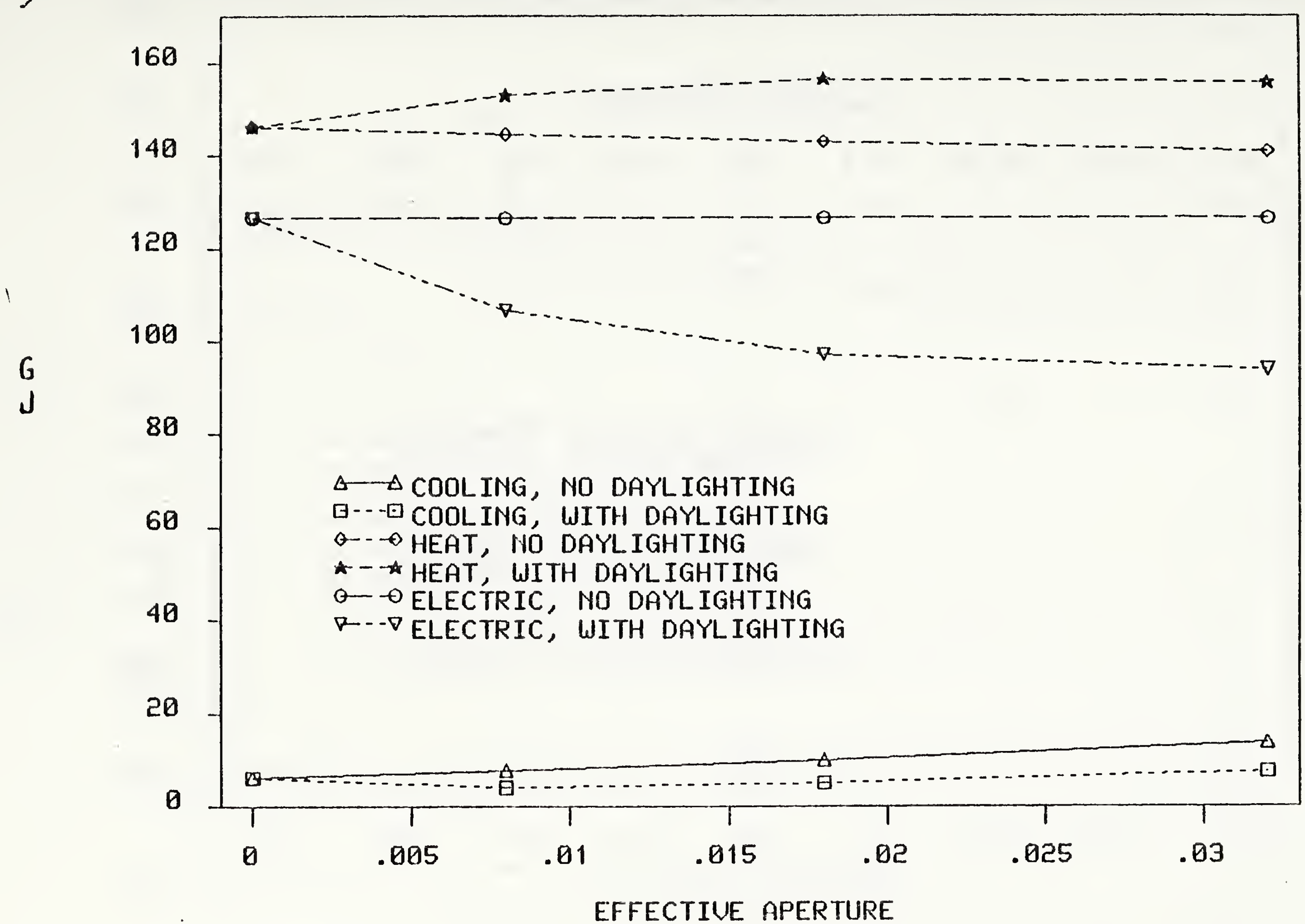


Figure 347. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
SOUTH SAWTOOTH, METAL ATTACHED

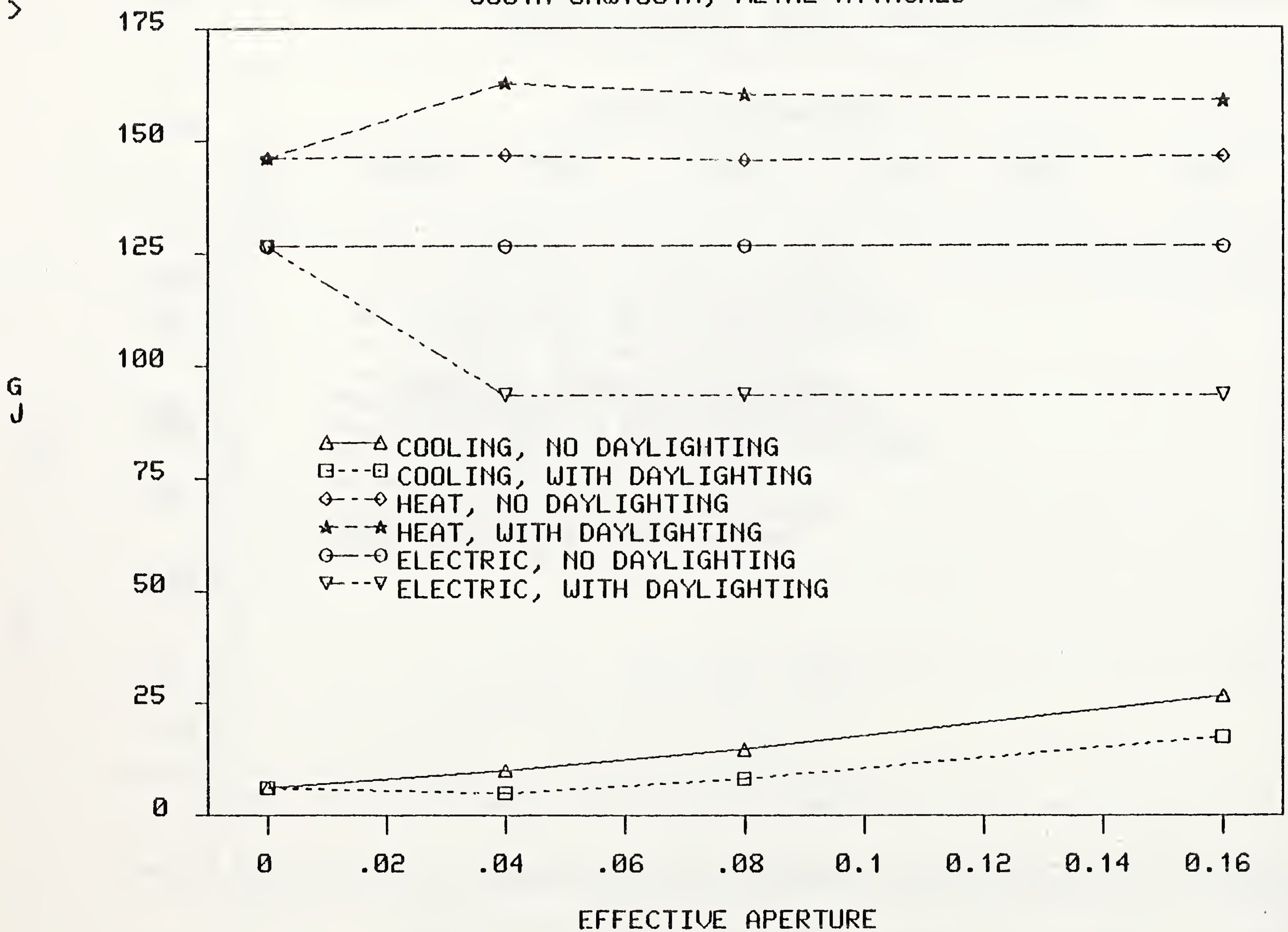


Figure 343. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
NORTH SAWTOOTH, METAL ATTACHED

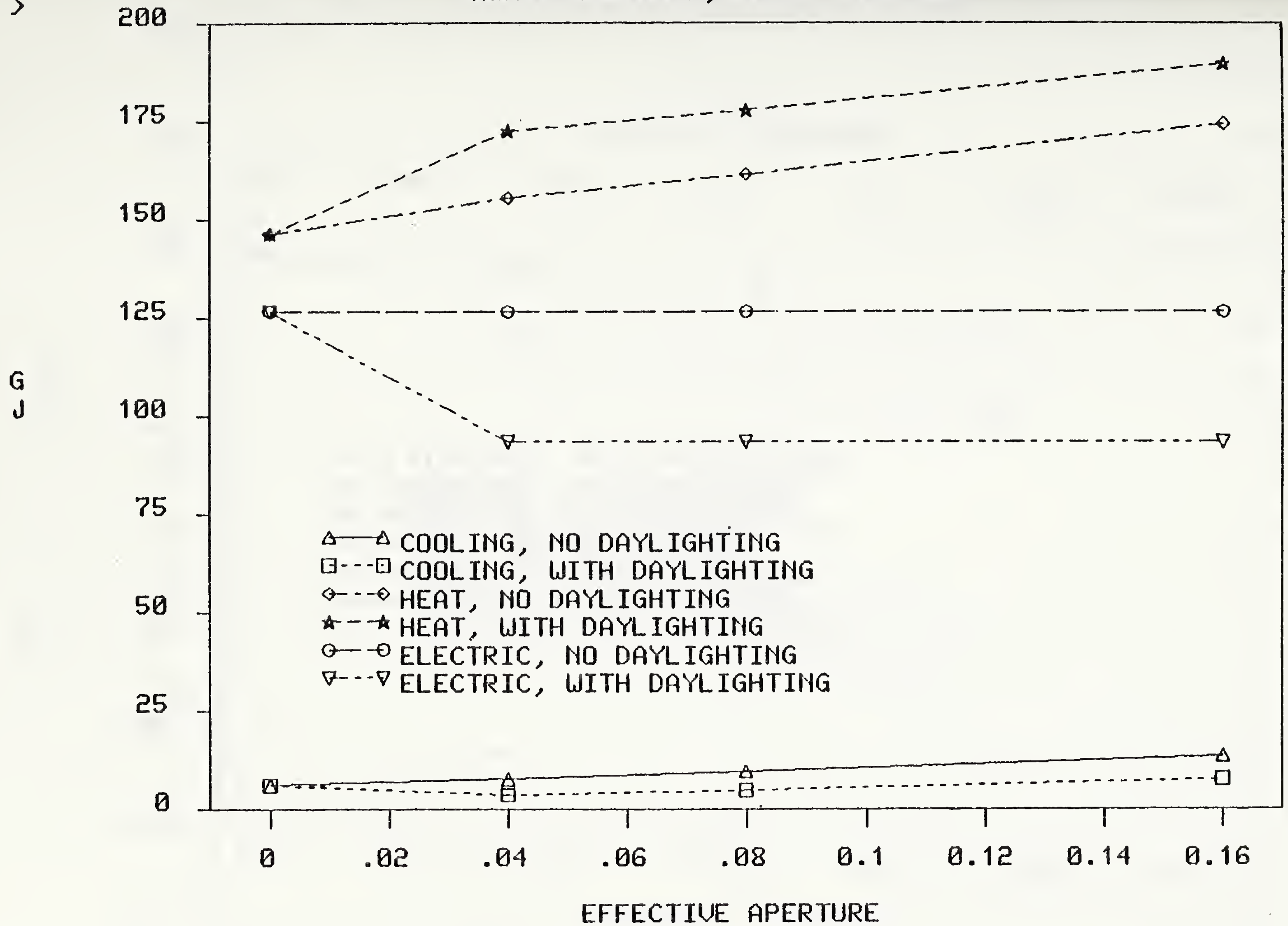


Figure 349. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle) SOUTH WINDOW, METAL ATTACHED

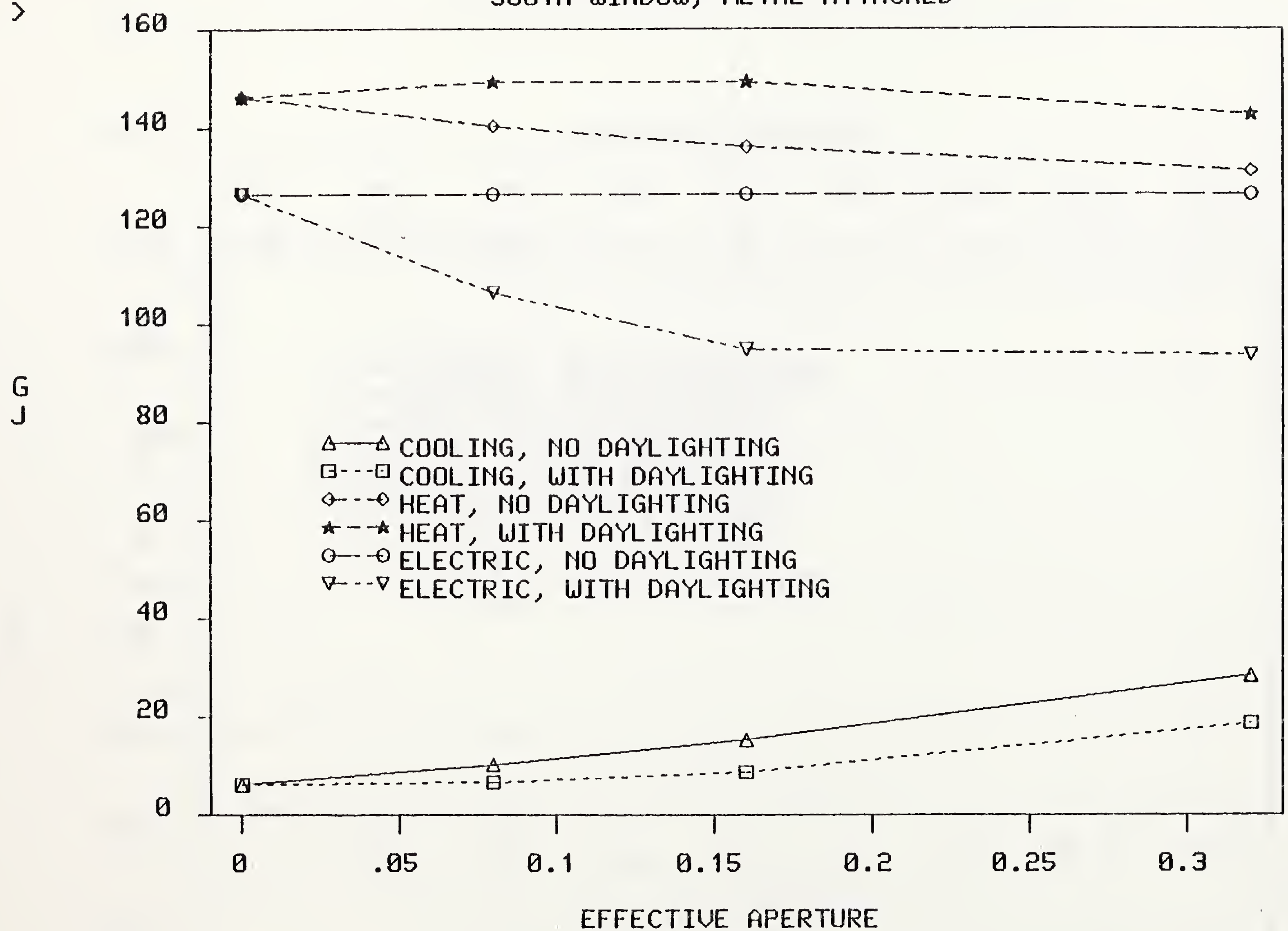


Figure 350. ANNUAL COOLING , HEATING AND ELECTRIC LOADS (Seattle)
NORTH WINDOW, METAL ATTACHED

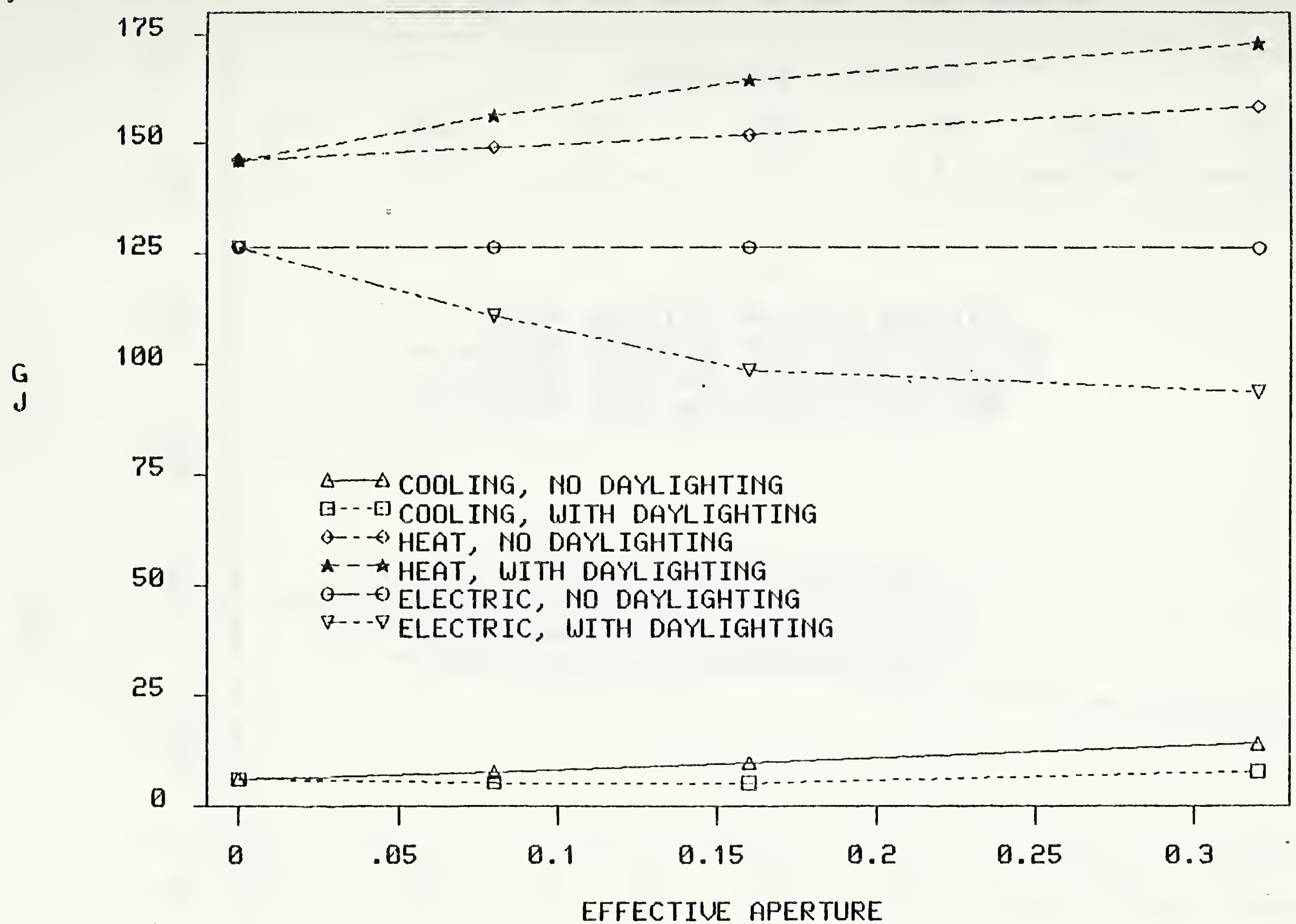


Figure 351. PEAK HEATING AND COOLING LOADS (Seattle) SKYLIGHTS, BRICK FREESTANDING

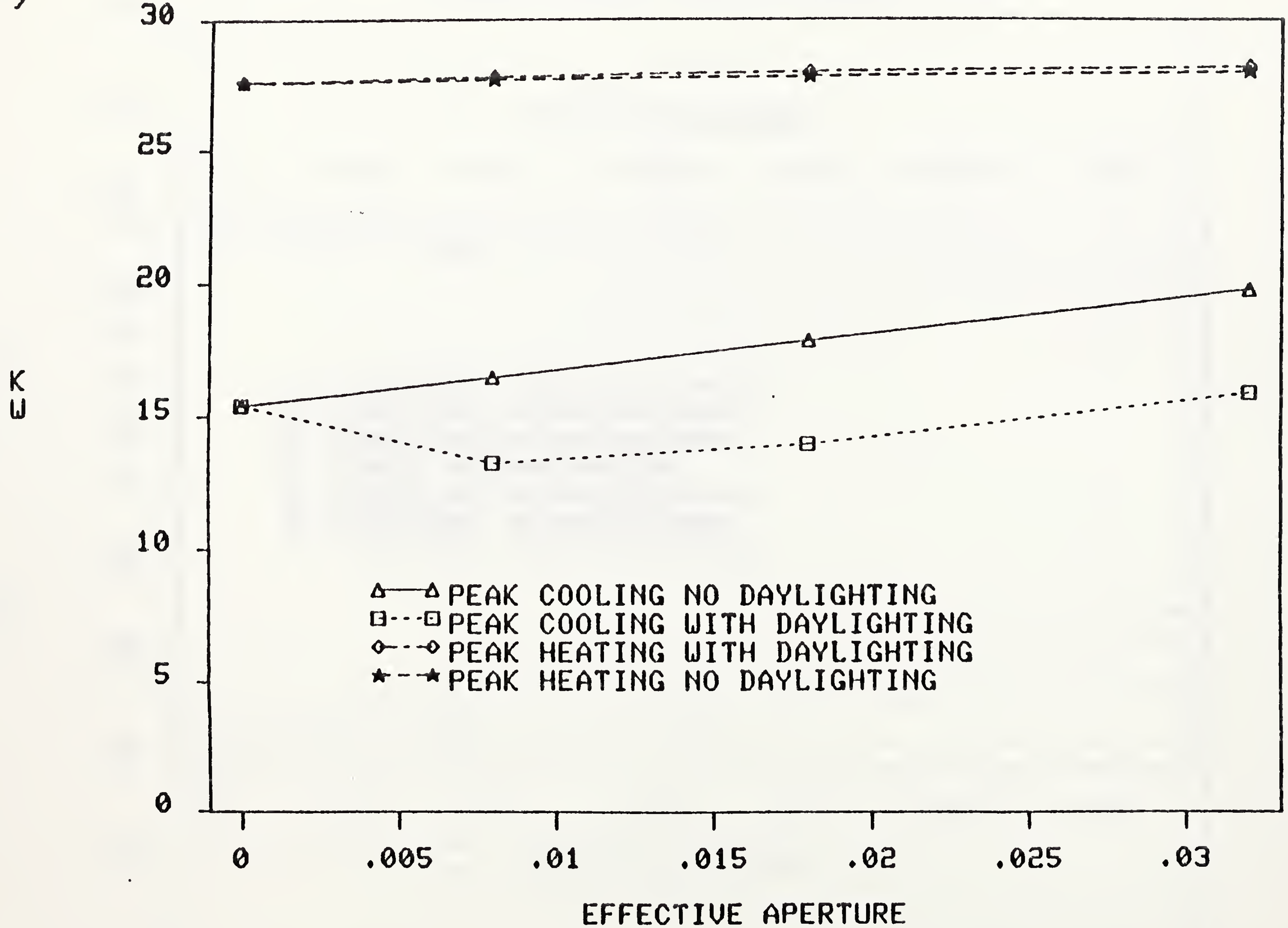


Figure 352. PEAK HEATING AND COOLING LOADS (Seattle)
SOUTH SAWTOOTH, BRICK FREESTANDING

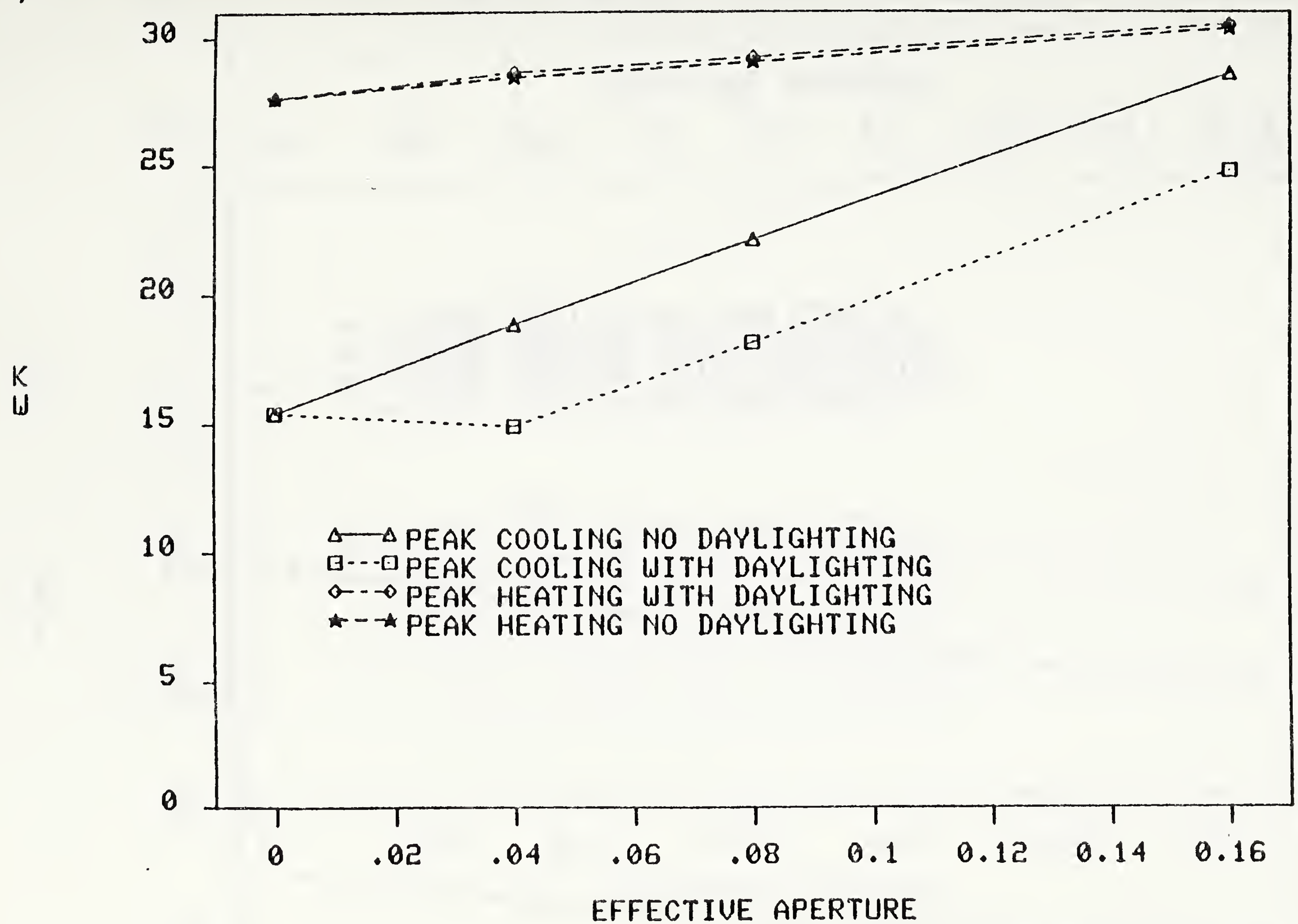


Figure 353. PEAK HEATING AND COOLING LOADS (Seattle)
NORTH SAWTOOTH, BRICK FREESTANDING

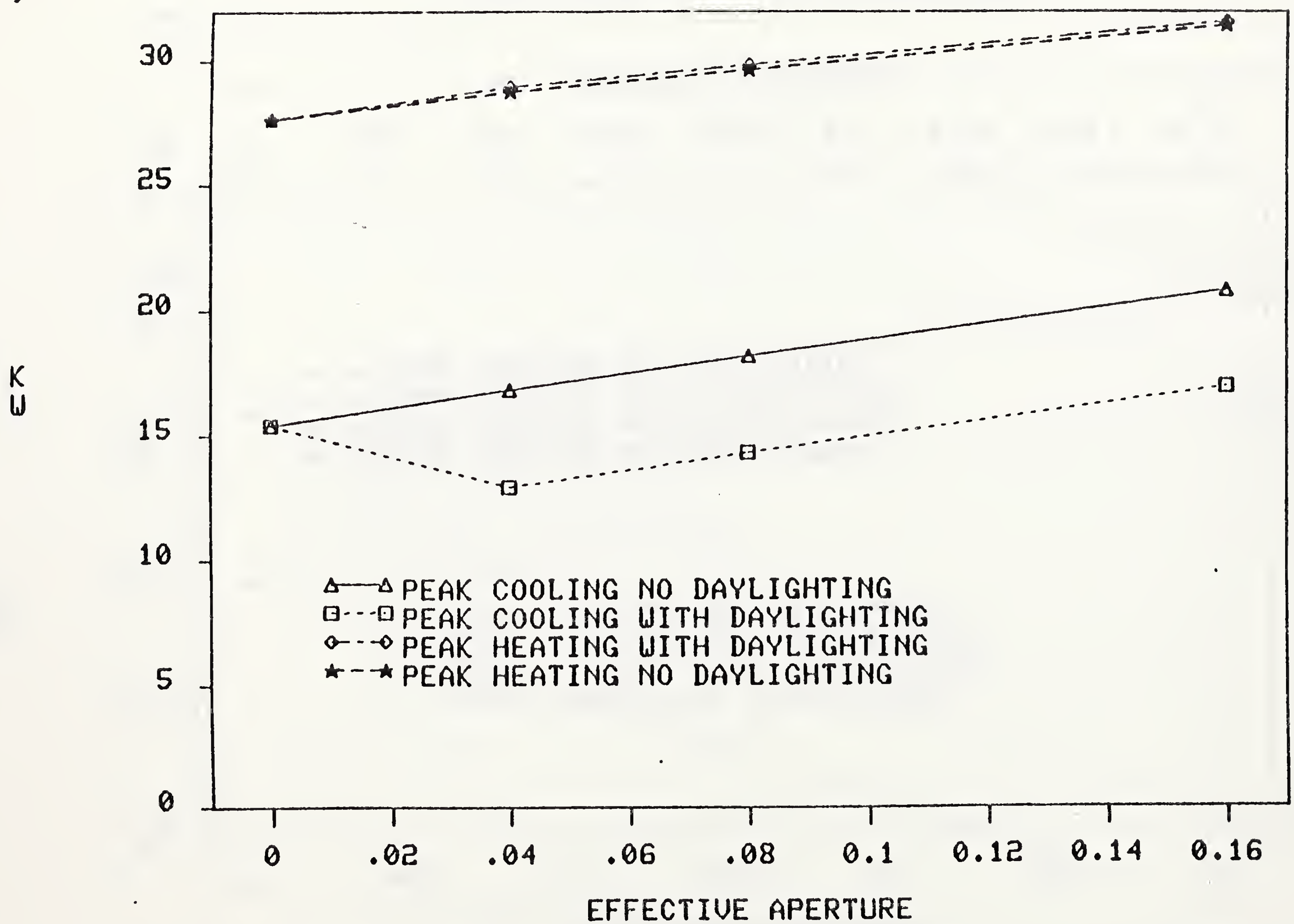


Figure 354. PEAK HEATING AND COOLING LOADS (Seattle)
SOUTH WINDOW, BRICK FREESTANDING

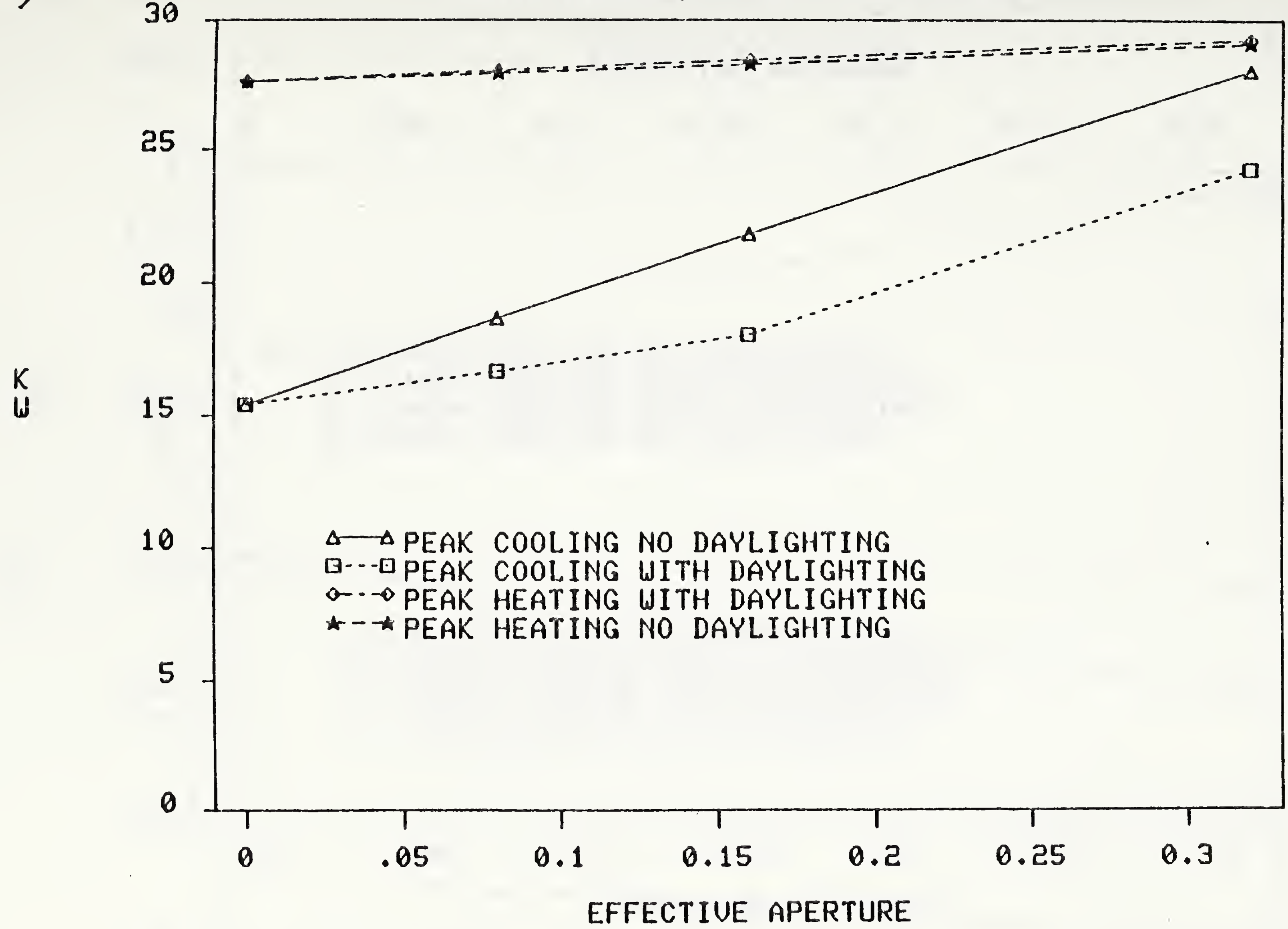


Figure 355. PEAK HEATING AND COOLING LOADS (Seattle)
NORTH WINDOW, BRICK FREESTANDING

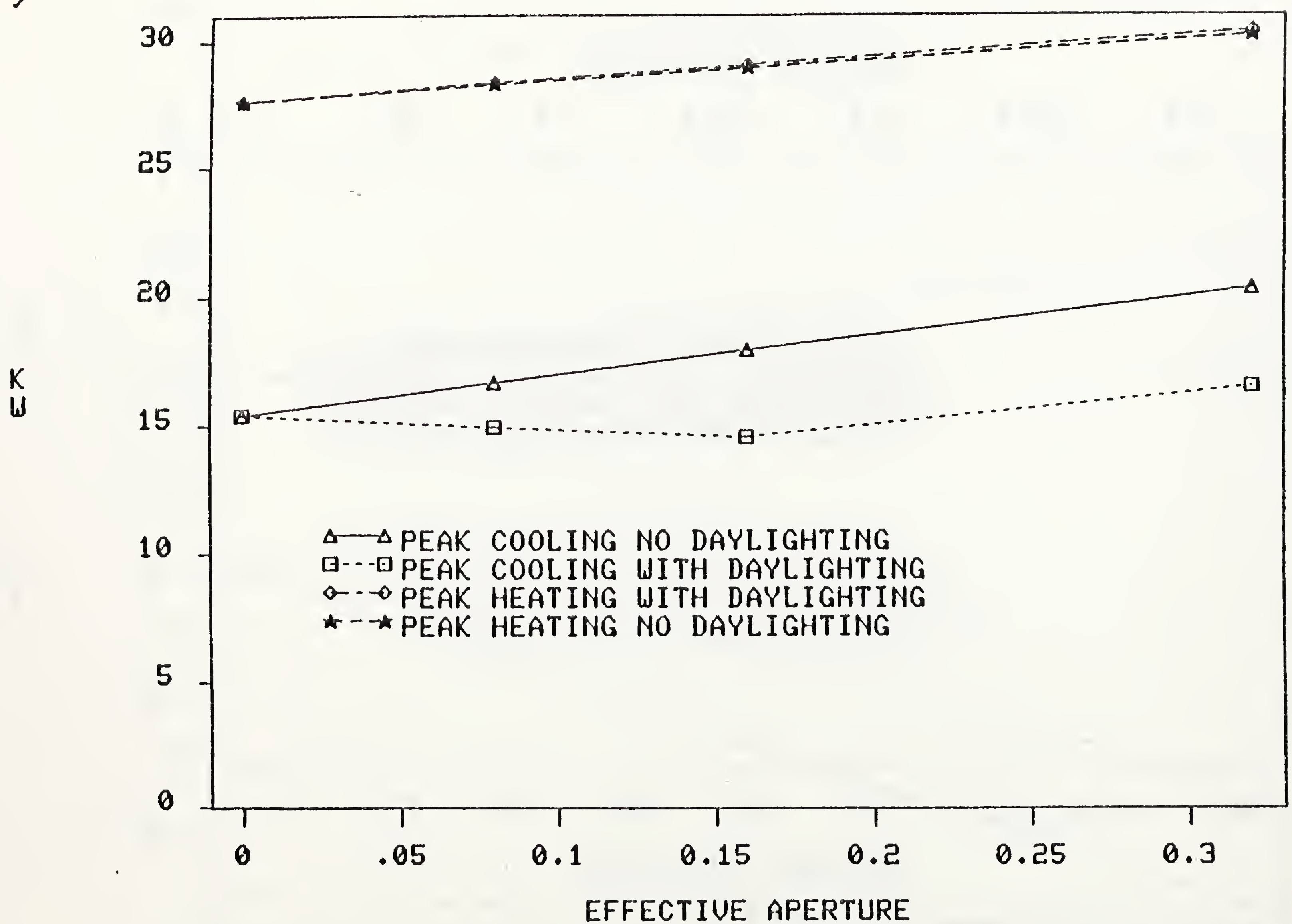


Figure 356. PEAK HEATING AND COOLING LOADS (Seattle)
SKYLIGHTS, BRICK ATTACHED

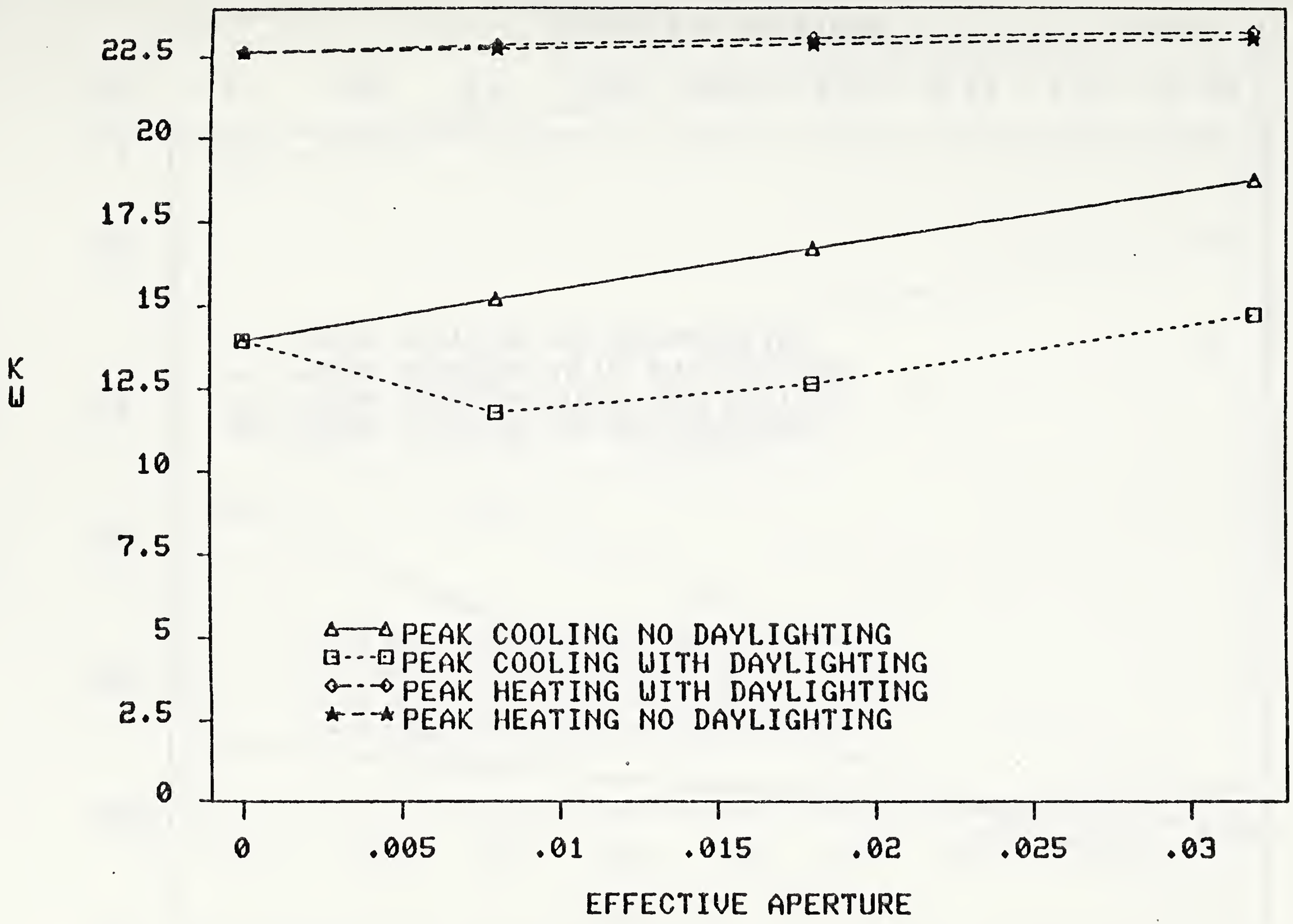


Figure 357. PEAK HEATING AND COOLING LOADS (Seattle) SOUTH SAWTOOTH, BRICK ATTACHED

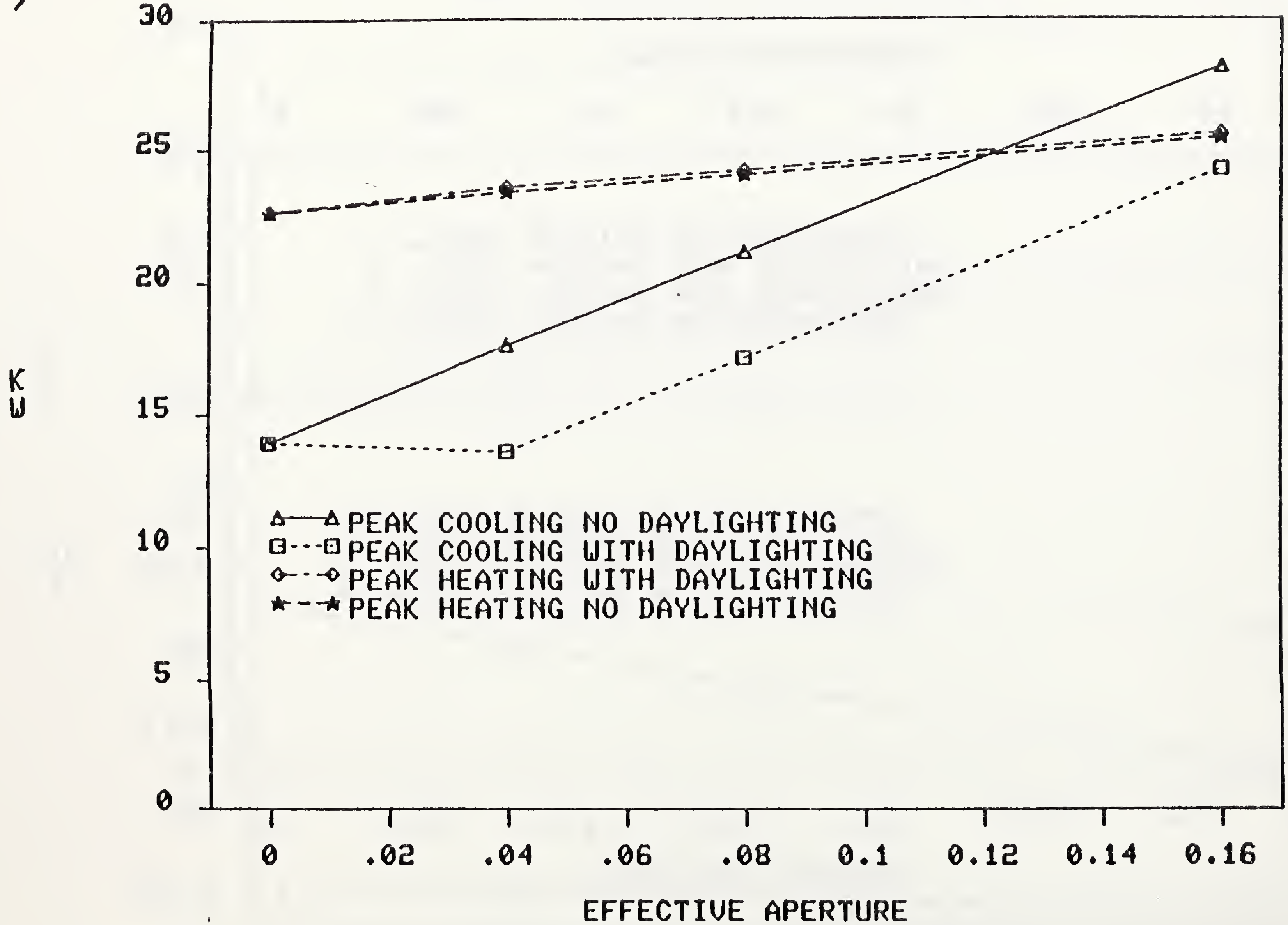


Figure 358. PEAK HEATING AND COOLING LOADS (Seattle)
NORTH SAWTOOTH, BRICK ATTACHED

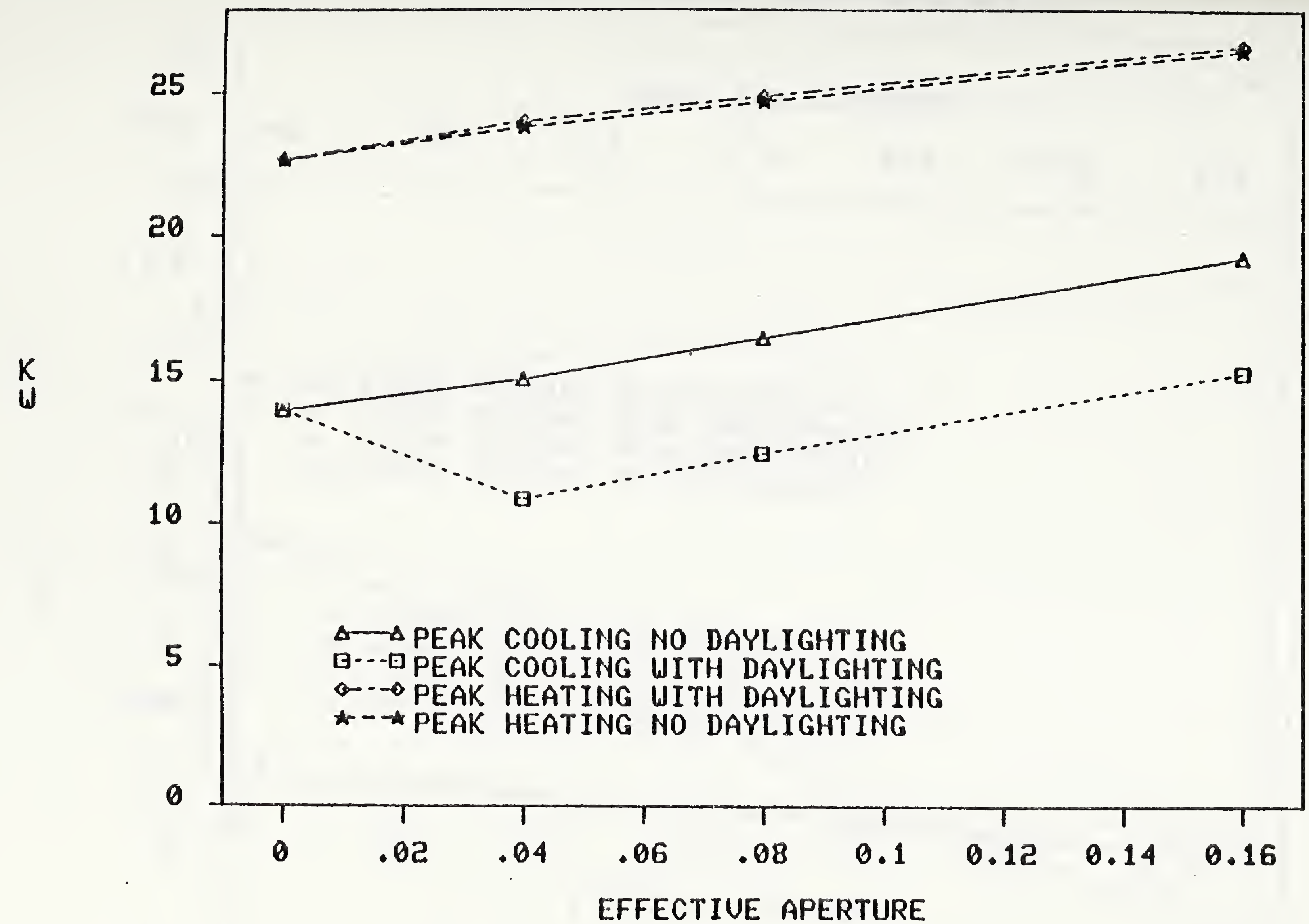


Figure 359. PEAK HEATING AND COOLING LOADS (Seattle)
SOUTH WINDOW, BRICK ATTACHED

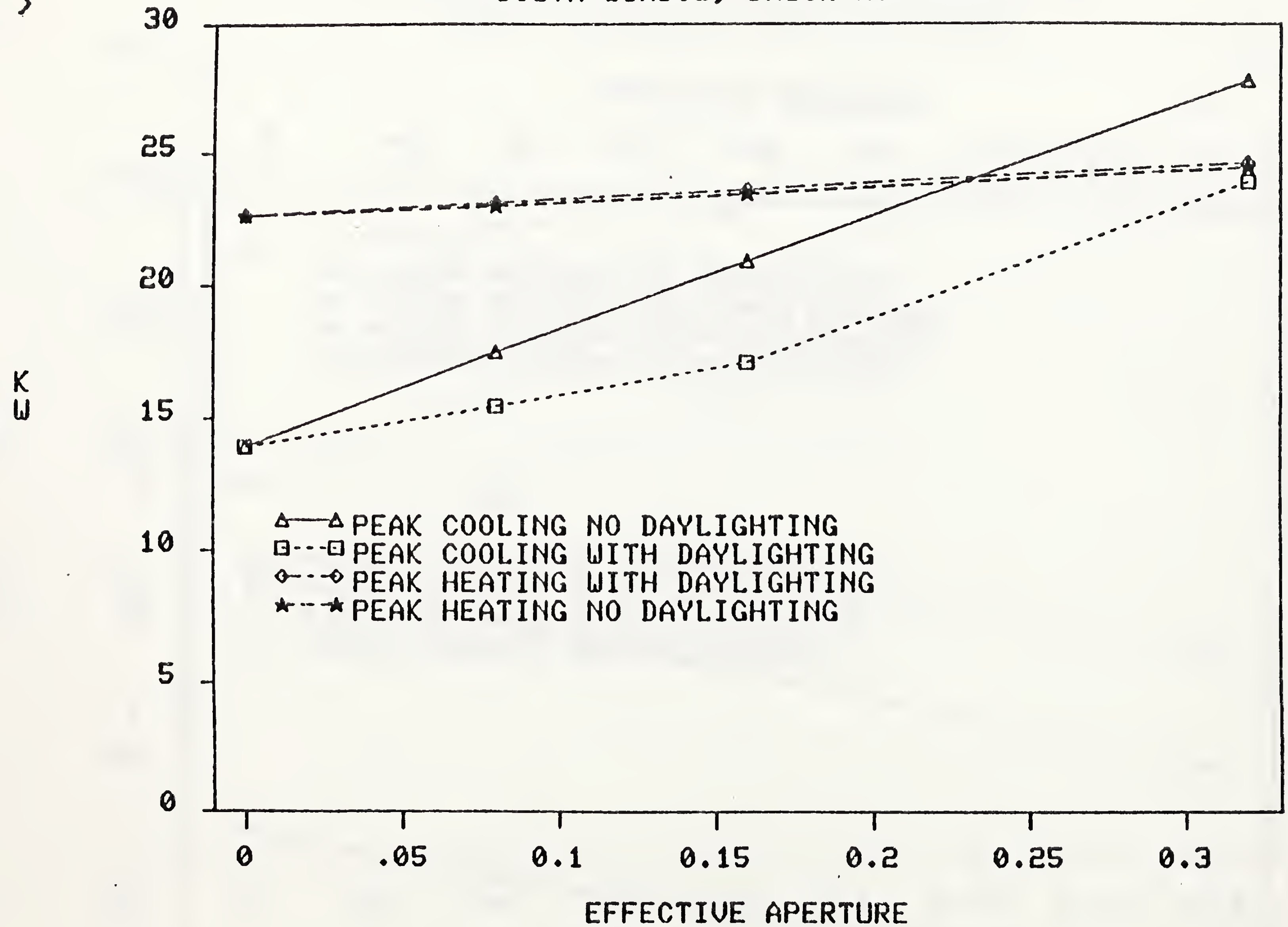


Figure 360. PEAK HEATING AND COOLING LOADS (Seattle)
NORTH WINDOW, BRICK ATTACHED

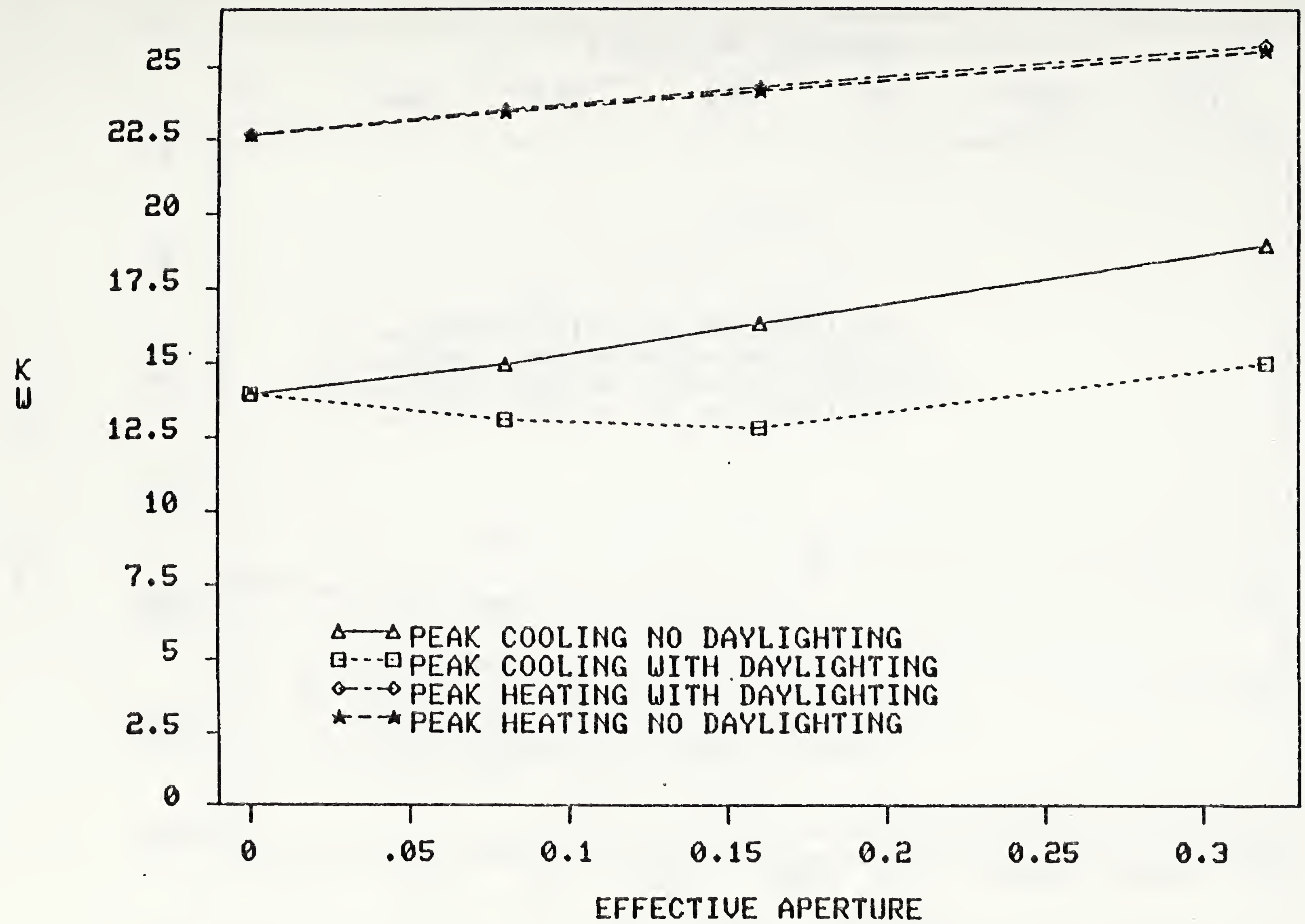


Figure 361. PEAK HEATING AND COOLING LOADS (Seattle)
SKYLIGHTS, METAL FREESTANDING

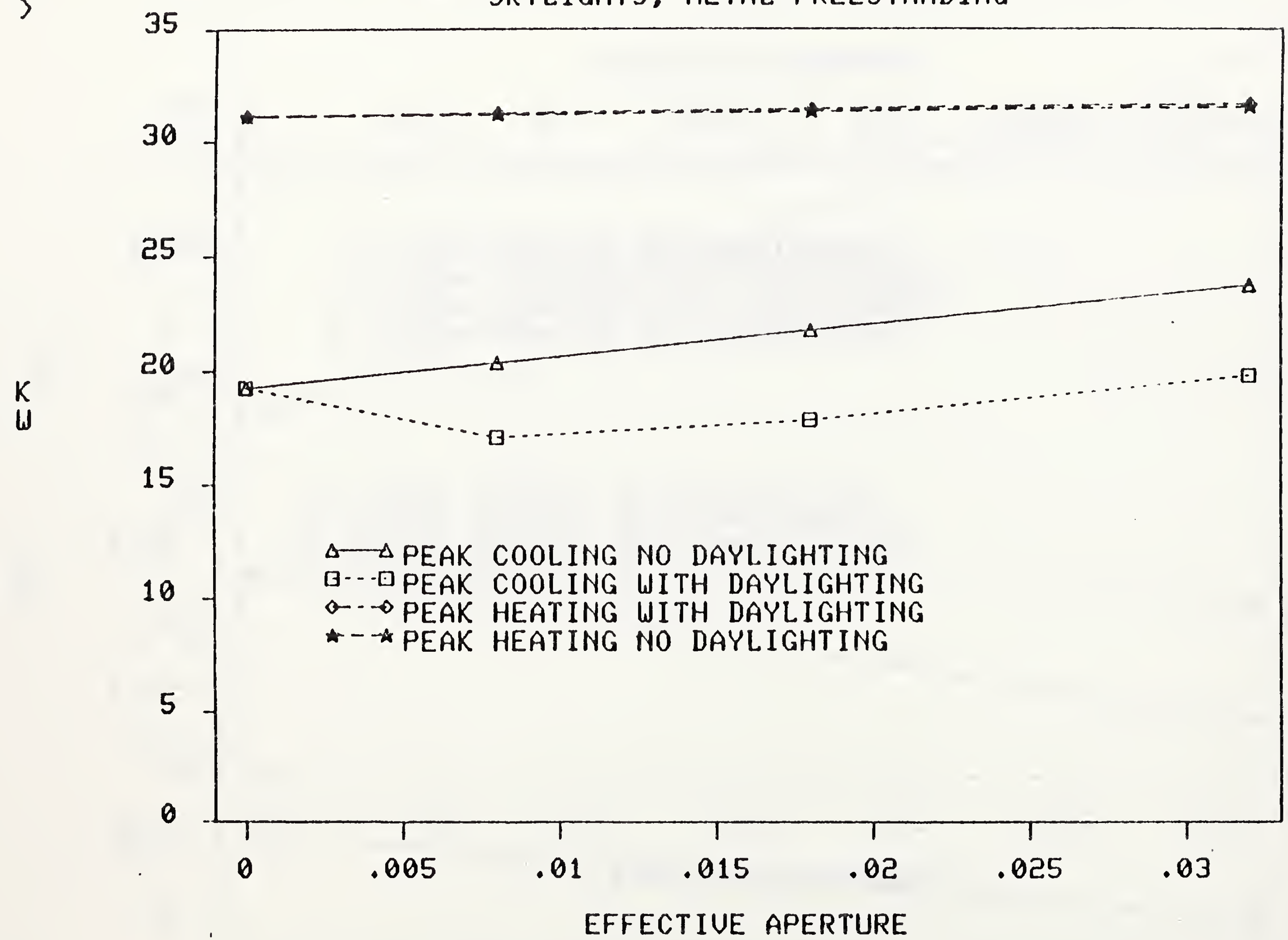


Figure 362. PEAK HEATING AND COOLING LOADS (Seattle)
SOUTH SAWTOOTH, METAL FREESTANDING

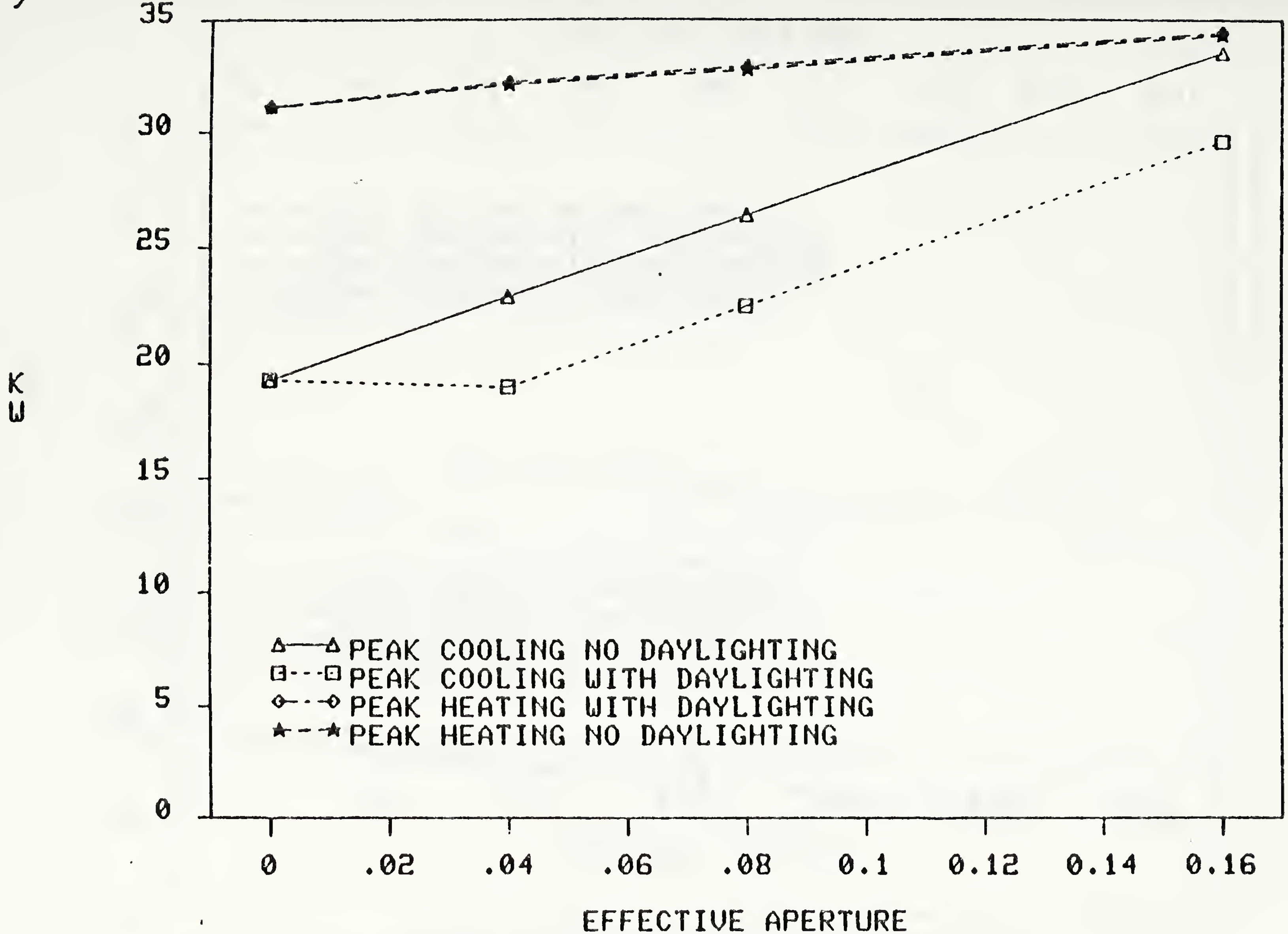
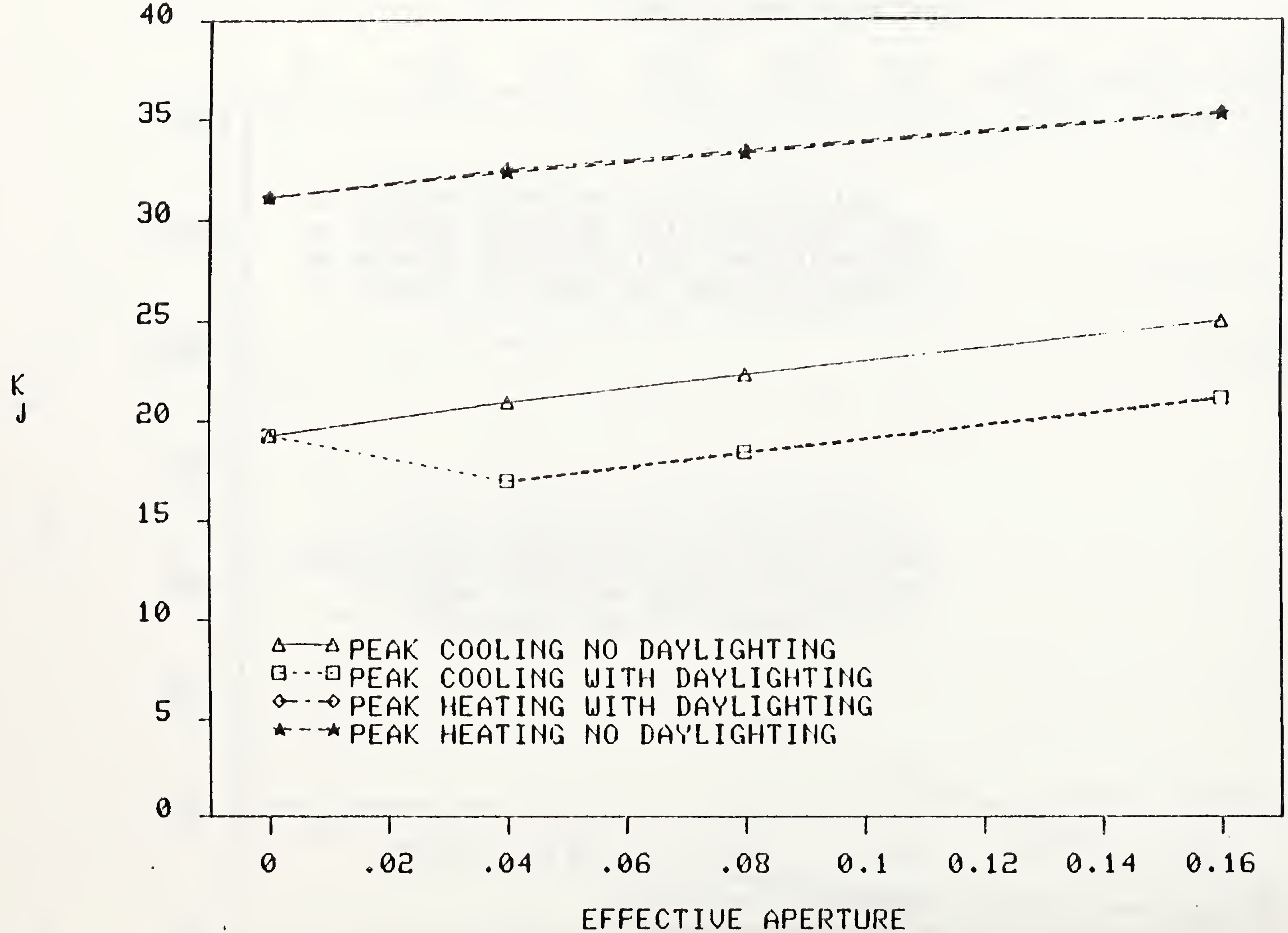


Figure 363. PEAK HEATING AND COOLING LOADS (Seattle)
NORTH SAWTOOTH, METAL FREESTANDING



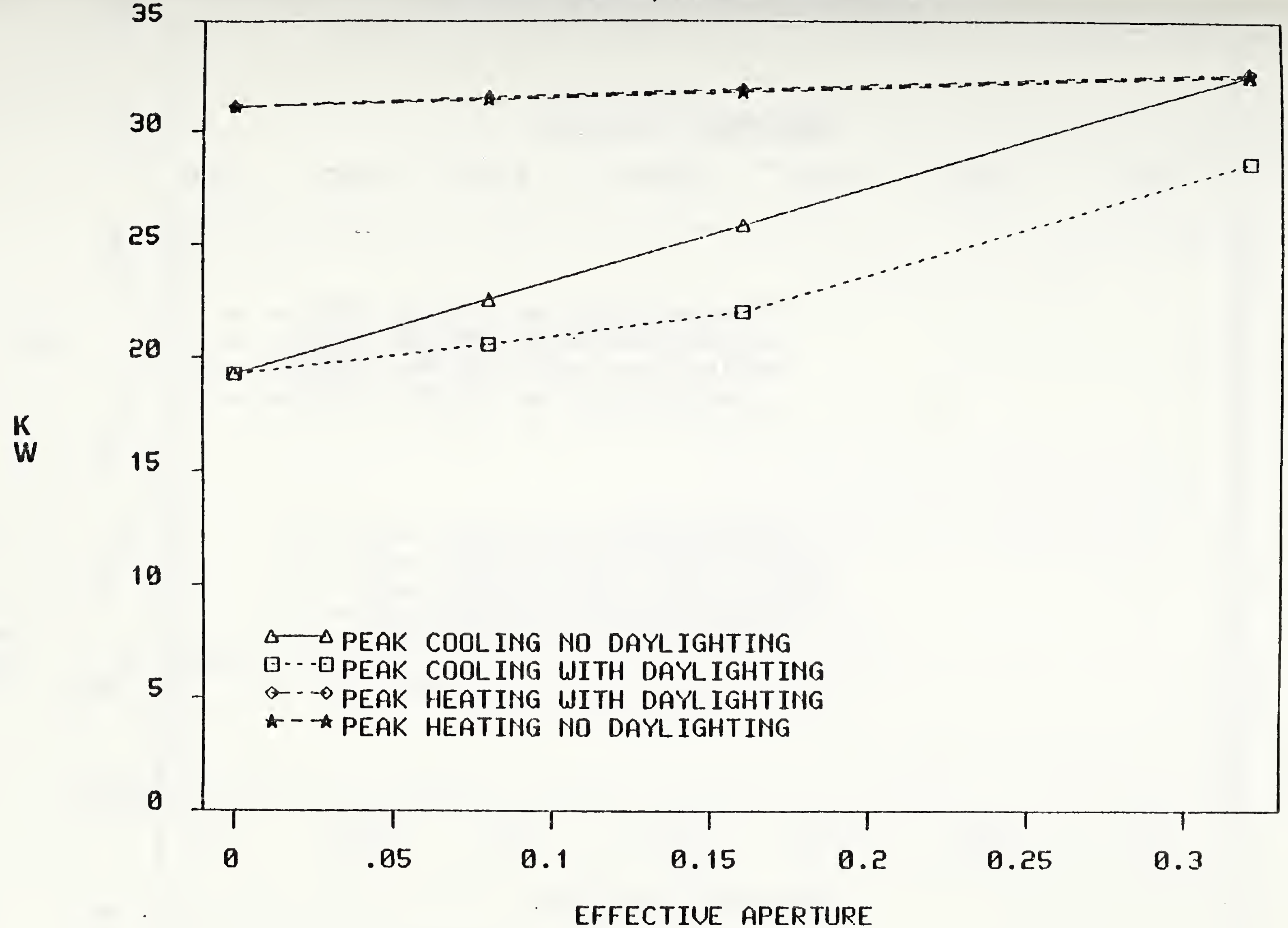



Figure 364. PEAK HEATING AND COOLING LOADS (Seattle)
SOUTH WINDOW, METAL FREESTANDING

Figure 365. PEAK HEATING AND COOLING LOADS (Seattle)
NORTH WINDOW, METAL FREESTANDING

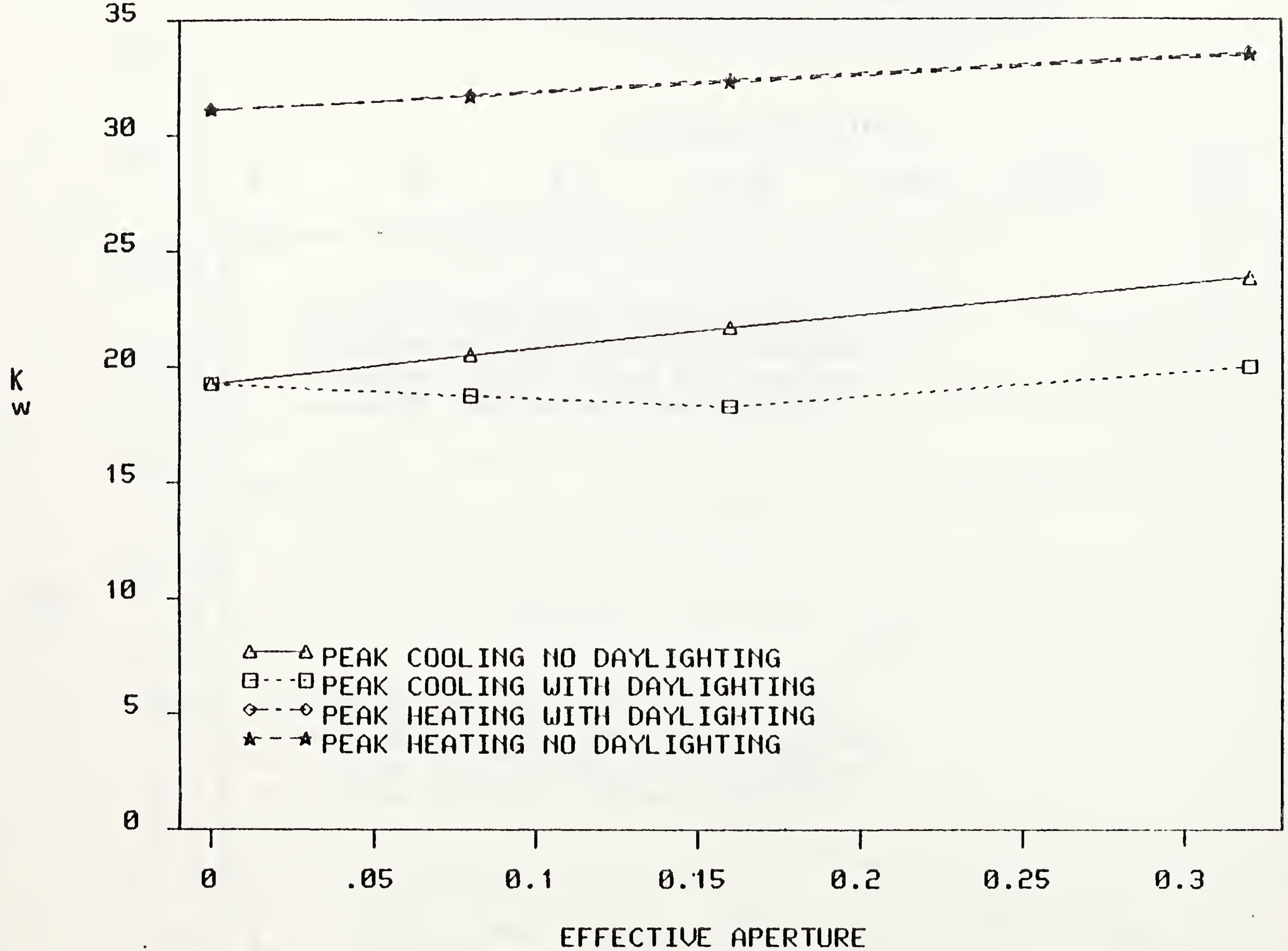


Figure 385. PEAK HEATING AND COOLING LOADS (Seattle)
SKYLIGHTS, METAL ATTACHED

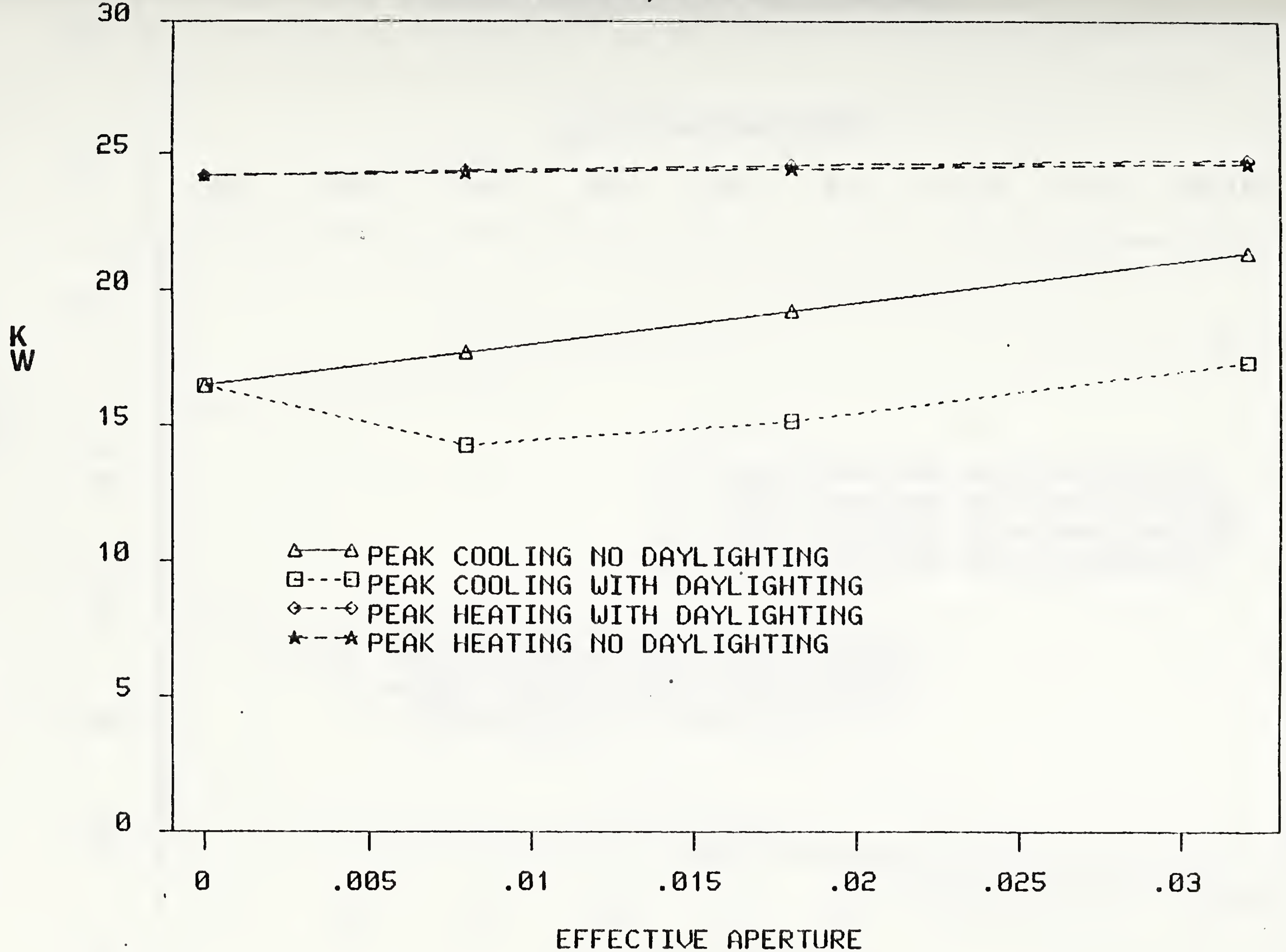


Figure 367. PEAK HEATING AND COOLING LOADS (Seattle)
SOUTH SAWTOOTH, METAL ATTACHED

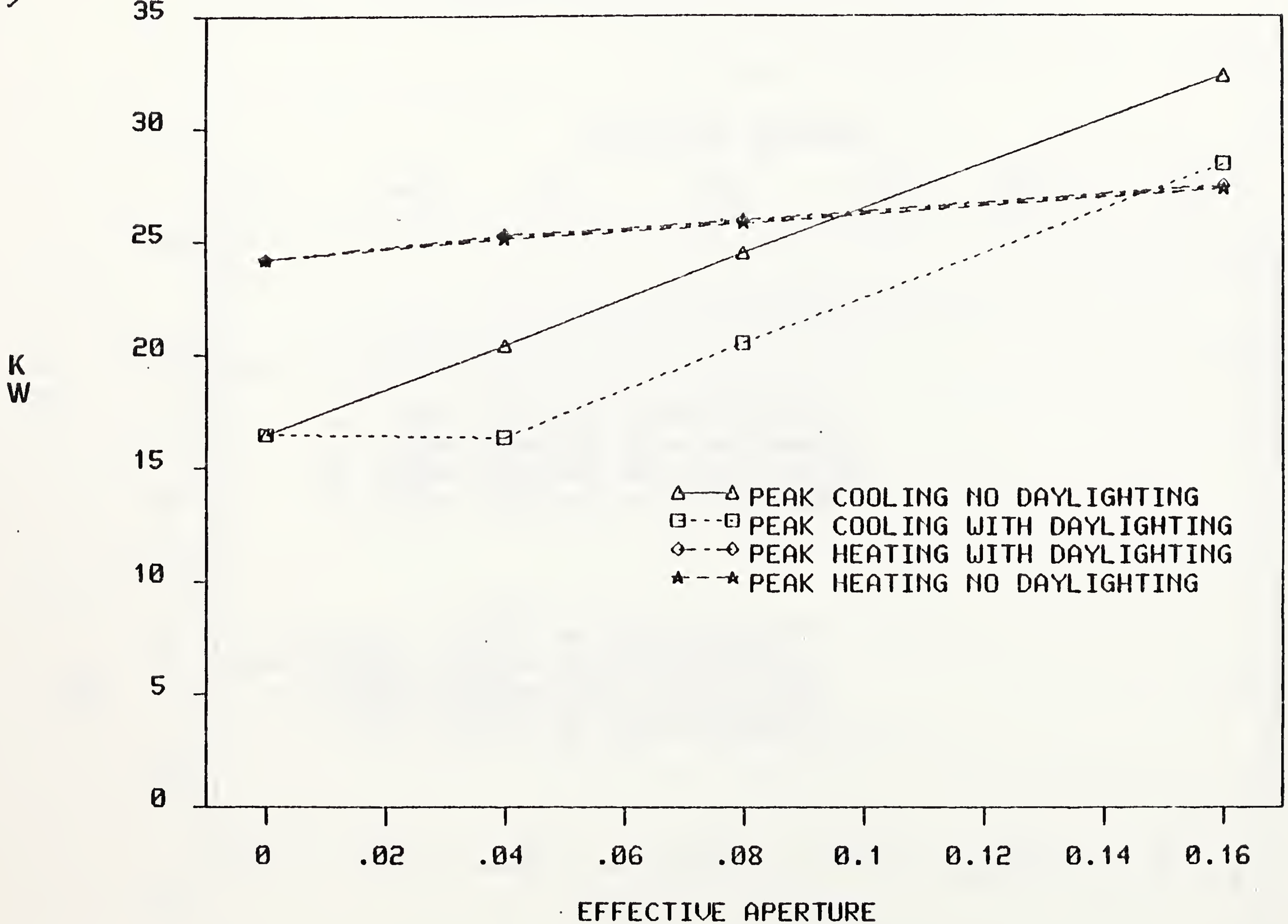


Figure 368. PEAK HEATING AND COOLING LOADS (Seattle)
NORTH SAWTOOTH, METAL ATTACHED

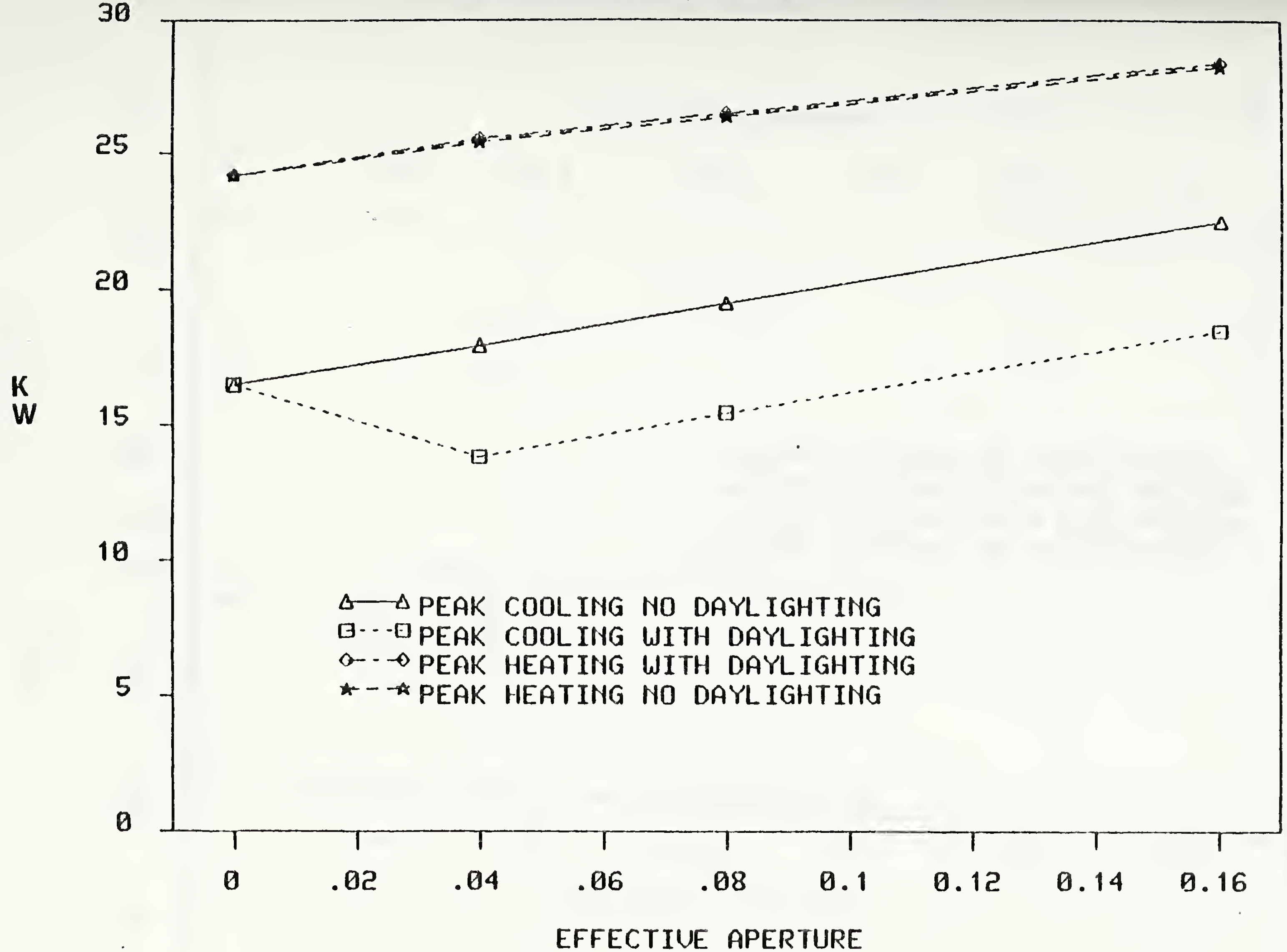


Figure 369. PEAK HEATING AND COOLING LOADS (Seattle)
SOUTH WINDOW, METAL ATTACHED

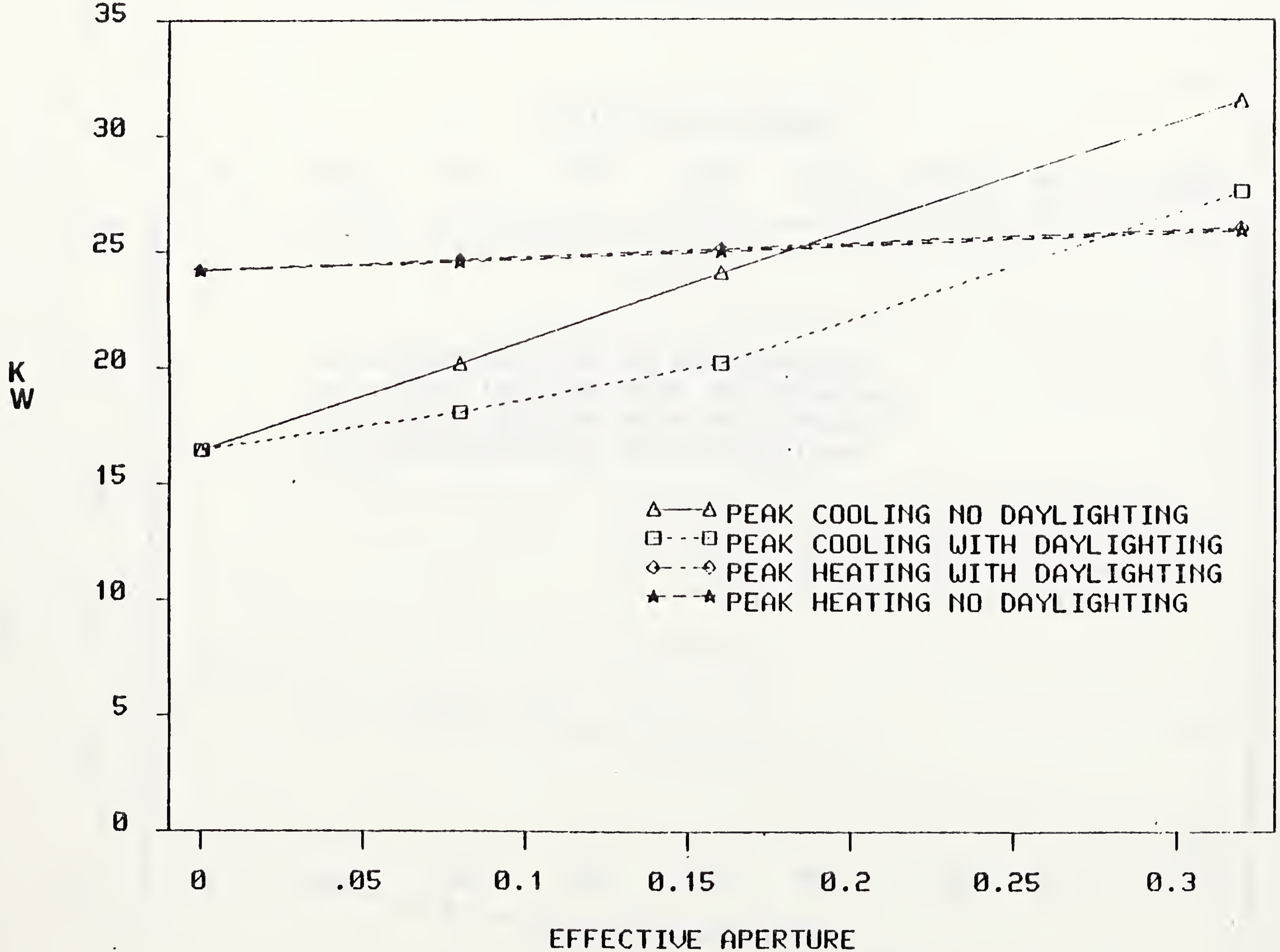
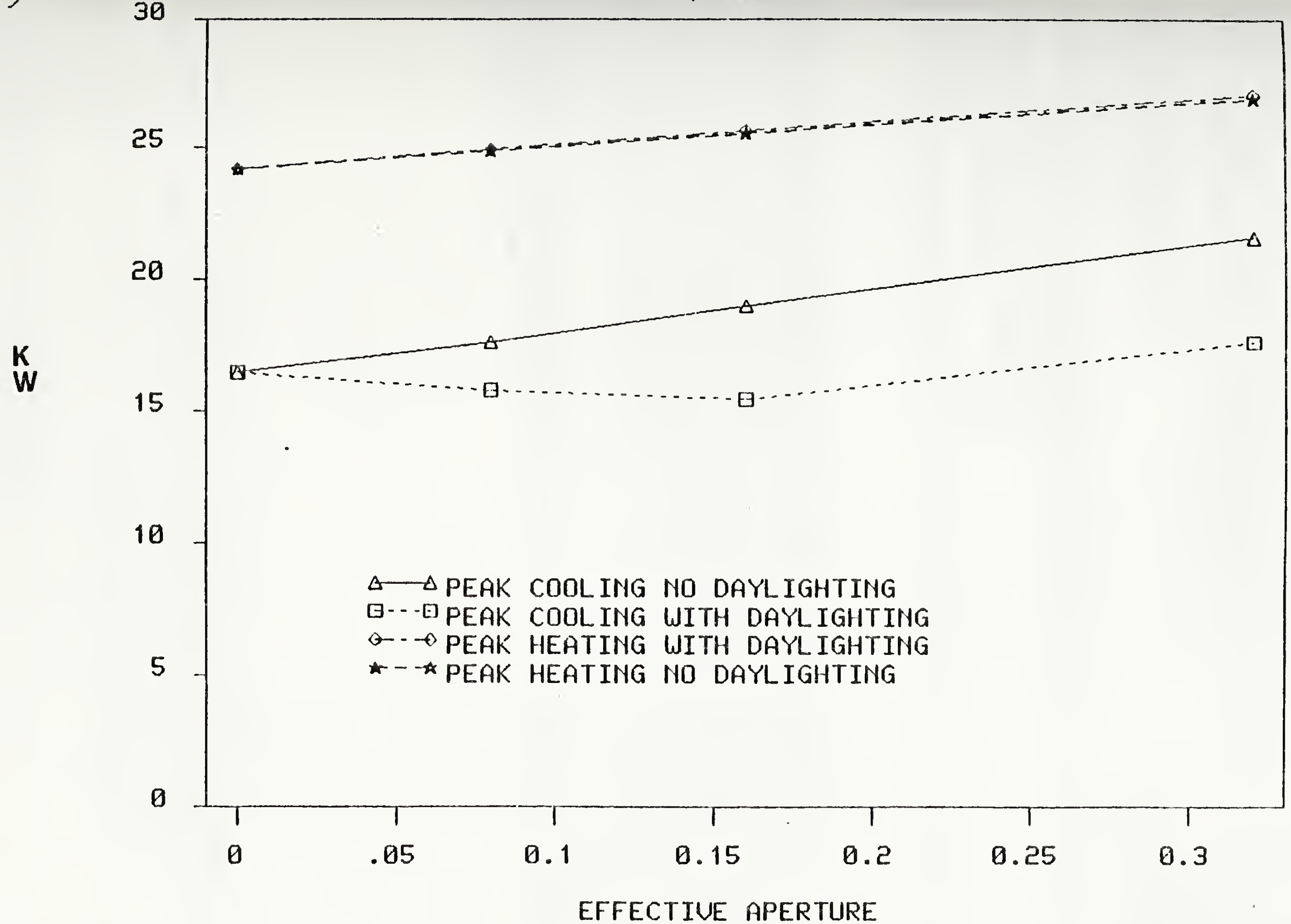


Figure 370. PEAK HEATING AND COOLING LOADS (Seattle)
NORTH WINDOW, METAL ATTACHED



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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report investigates the relationship between building energy requirements for heating, cooling and lighting, and building fenestration design. Particular emphasis is given to the effect of the use of daylight to offset electric lighting needs. The computer simulation procedure used for the analysis is a hybrid version of BLAST and CEL-1, which allows detailed modeling of building heat transfer, HVAC systems, and lighting systems.

The evaluation encompasses five locations, and the results are presented in the form of generalized design guidelines and figures, on the basis of building thermal mass and exposed wall area.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Daylighting, energy, fenestration, illuminance, skylight, window.

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